Deep Underground Laboratories and neutrino beams European facilities

S. Katsanevas
IN2P3

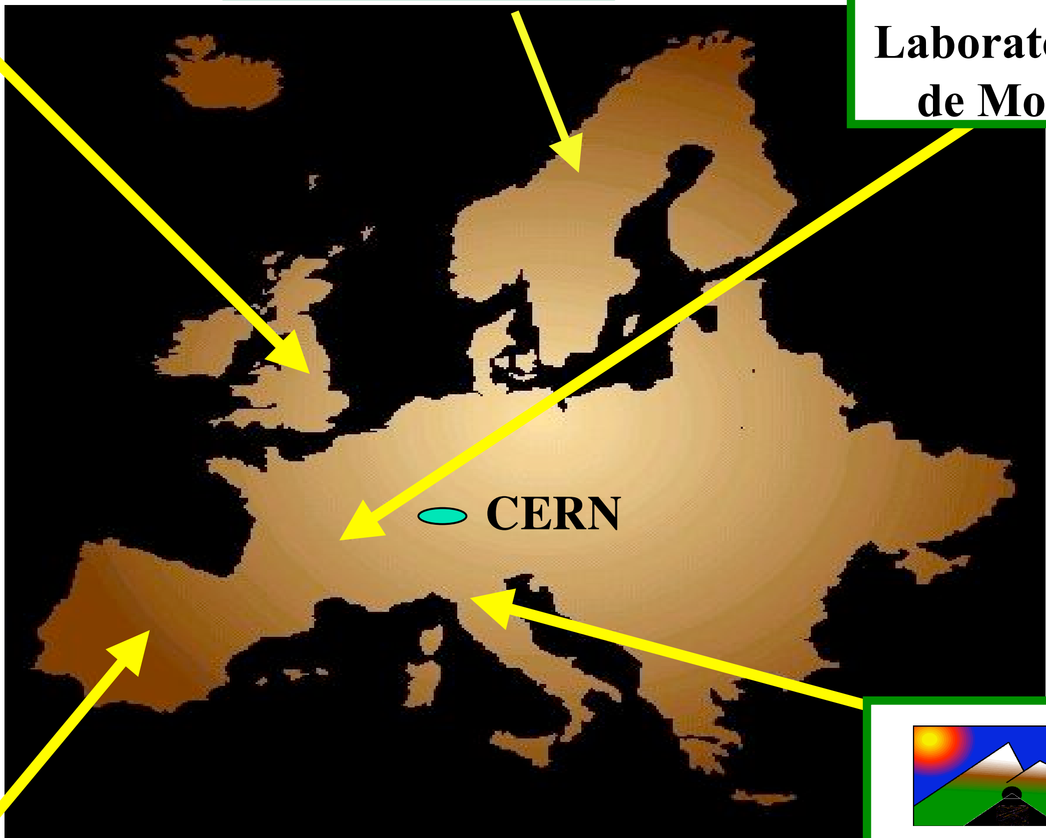
Thanks to Mezzetto, Bouchez, Mosca, Rubbia, Ronga, Cazes, Lindroos,Cadenas, Migliozzi,Rigolin,…

European Deep Underground Laboratories

Institute of Underground Science in Boulby mine, UK

Pyhasalmi mine
Finland

Laboratoire Souterrain de Modane, France



+Polkowice

Mine Poland

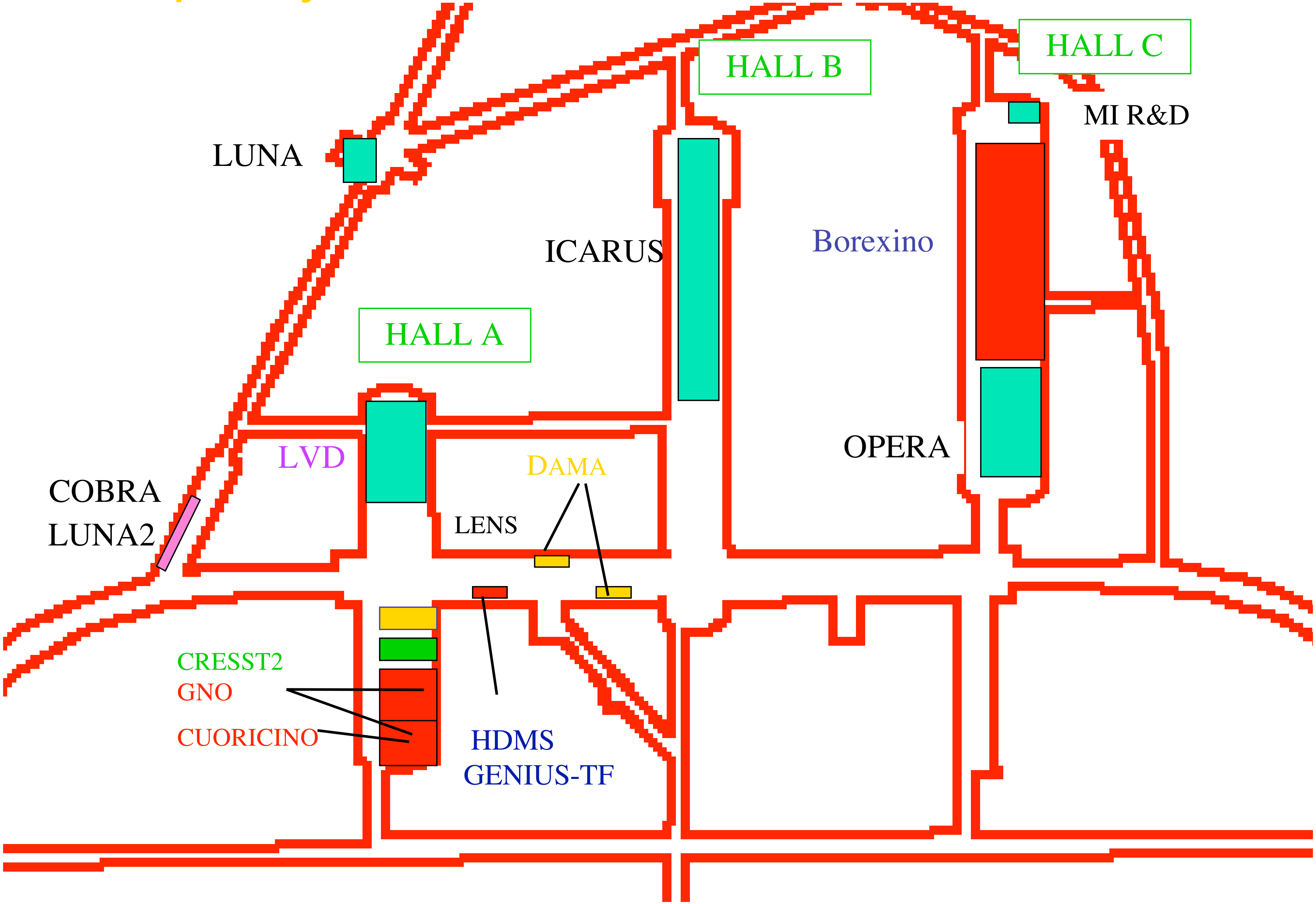
LSC

Laboratorio Subterraneo de Canfranc, Spain

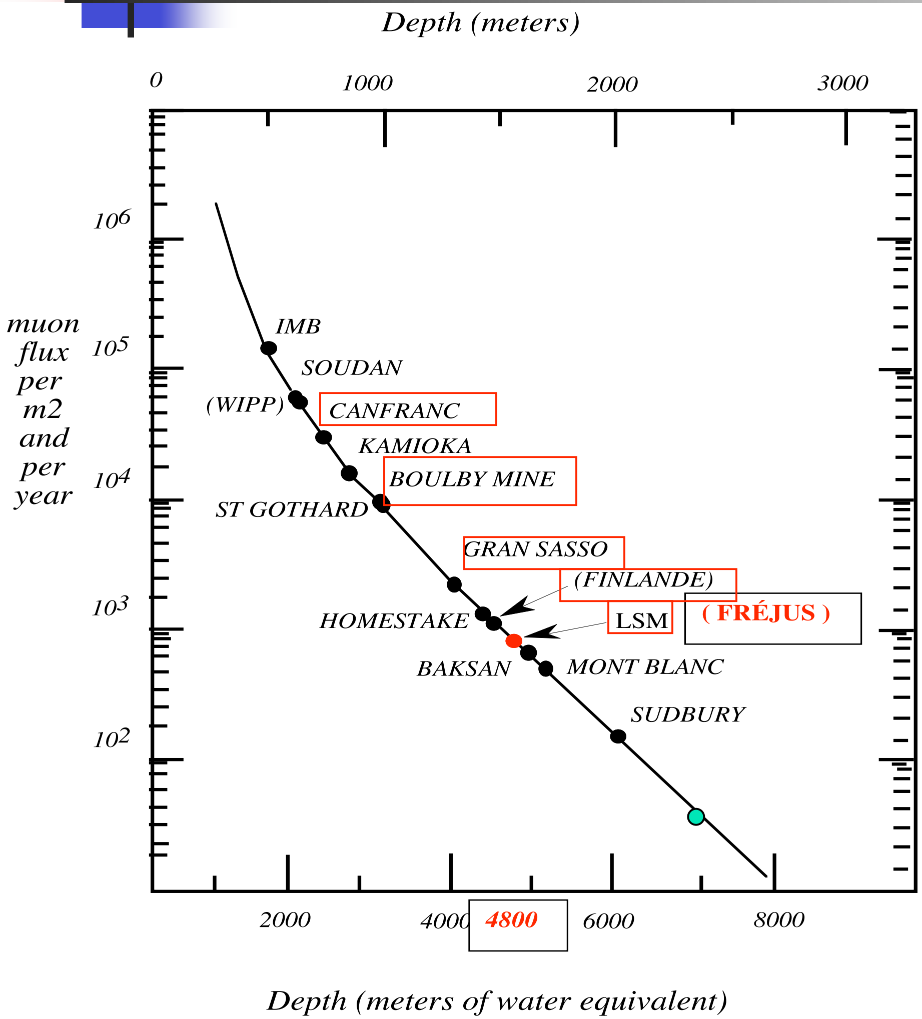
LNGS

Laboratori Nazionali del Gran Sasso, Italy

Occupancy LNGS



Current physics topics



- Neutrino long baseline
  - LNGS (OPERA,ICARUS)
- Solar Neutrino
  - LNGS (Borexino)
- Neutrinoless double beta
  - **LNGS (CUORE, GENIUS)**
  - **LSM (NEMO3)**
  - **LSC(IGEX)**
- **Dark Matter**
  - **LSM (EDELWEISS)**
  - **LNGS(DAMA, CRESST, HDMS)**
  - **Boulby (NAIAD,ZEPLIN,DRIFT)**
  - **LSC (IANAIS,Rosebud,IGEX)**
- **Supernova +Astrophysics**
  - **LNGS (LVD, LUNA,Borexino,…)**

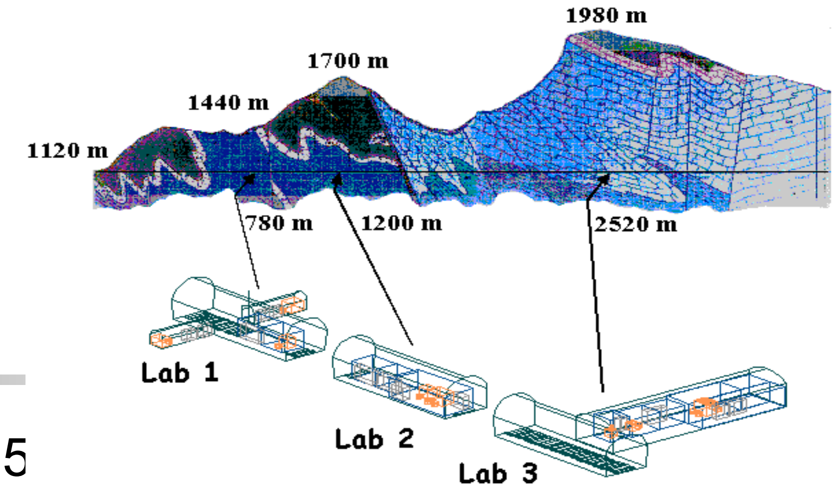
Laboratory news

- Gran Sasso is slowly going out of the judicial control. The extra floor has finished.
  - The ICARUS cryostat entered the lab !!!
  - Borexino filling in Spring?
- Fréjus and Canfranc will have a new building in the next few years

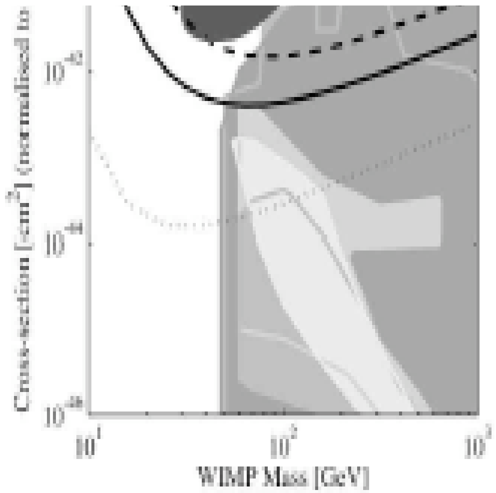
Institutional framework

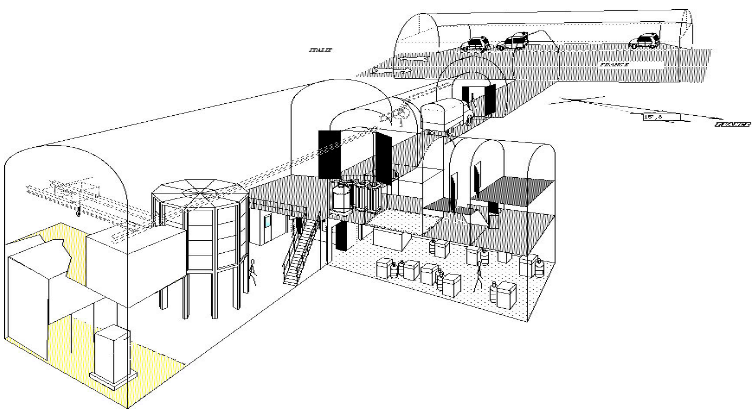
- **Astroparticle Physics European Coordination ApPEC (major european agencies)**
  - Reviews, urges for coordination and prepares roadmap for: double beta decay and dark matter, also megatonne type detectors?
- **European program ILIAS (since 2004) funds**
  - Networking of underground labs, double beta and dark matter
  - R&D of Double beta decay and low radioactivity techniques
- **The 7th European Research Framework (2007) will be certainly a major player**
  - Major? construction funds will be available
  - European Strategy Forum Research Infrastructures (ESFRI): **roadmaps** an important tool
  - Recently approved KM3 Design Study gives a headstart to neutrino telescopes
- **Not yet a clear framework in Europe for a neutrino oscillation roadmap**
  - CERN committees play a major role (see recent Villars SPSC meeting and recommandations)
  - European funded Beam R&D Networks is important (CARE, EURISOL)
  - But, the decision involves the future of non-accelerator infrastructures, and certainly a rich non-accelerator physics potential (proton decay, supernova and astrophysics observatory). A more general strategy has to be defined
  - European workshops (NOVE, NOW) and wordwide Nufact and NNN (see NNN05 in Aussois 7-9 April) are also important fora

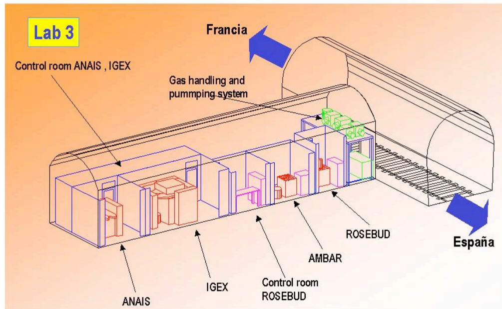
Dark matter

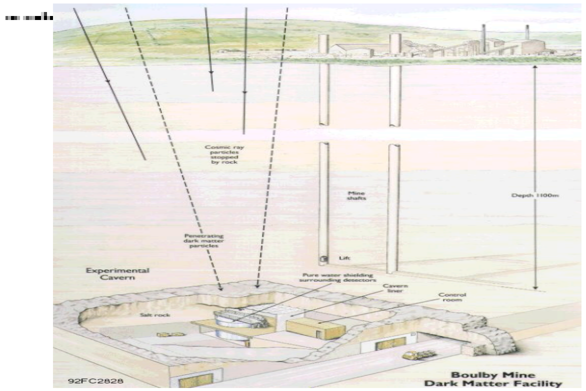


- EDELWEISS II starting September 2005
- Common Design study EDELWEISS/CRESST in preparation
- ZEPLIN published preminimary results
- Xe work in progress
- Review of status by PRC of ApPEC in Barcelona, 20-21 jan 2005.





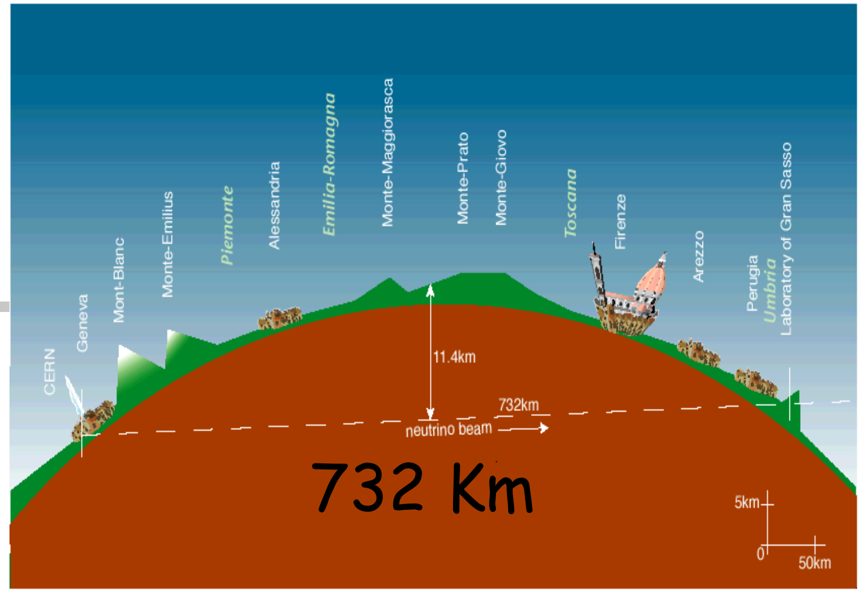




Long Baseline CNGS

- Provide an unambiguous evidence for $\nu_\mu \rightarrow \nu_\tau$ oscillations in the region of atmospheric neutrinos by looking for ν_τ appearance in a pure ν_μ beam

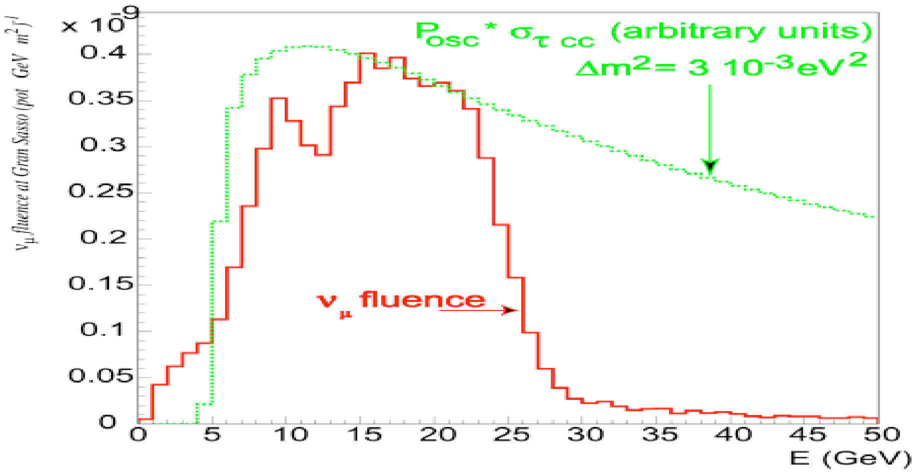
➤ Search for the subleading $\nu_\mu \rightarrow \nu_e$ oscillations (measurement of Θ_{13})



Given the distance (732 Km):

ν_μ flux **optimized** for the maximal number of ν_τ charged current interactions

$<E\nu_\mu>$	17 GeV
$(\nu_e+\overline{\nu}_e)/\nu_\mu$	0.87%
$\overline{\nu}_\mu$ / ν_μ	2.1%
ν_τ prompt	negligible



CNGS1: OPERA emulsion

CNGS2: ICARUS LAr

Civil Engineering
excavate civil engineering pit, tunnels and caverns; concrete / shot-crete tunnels and caverns

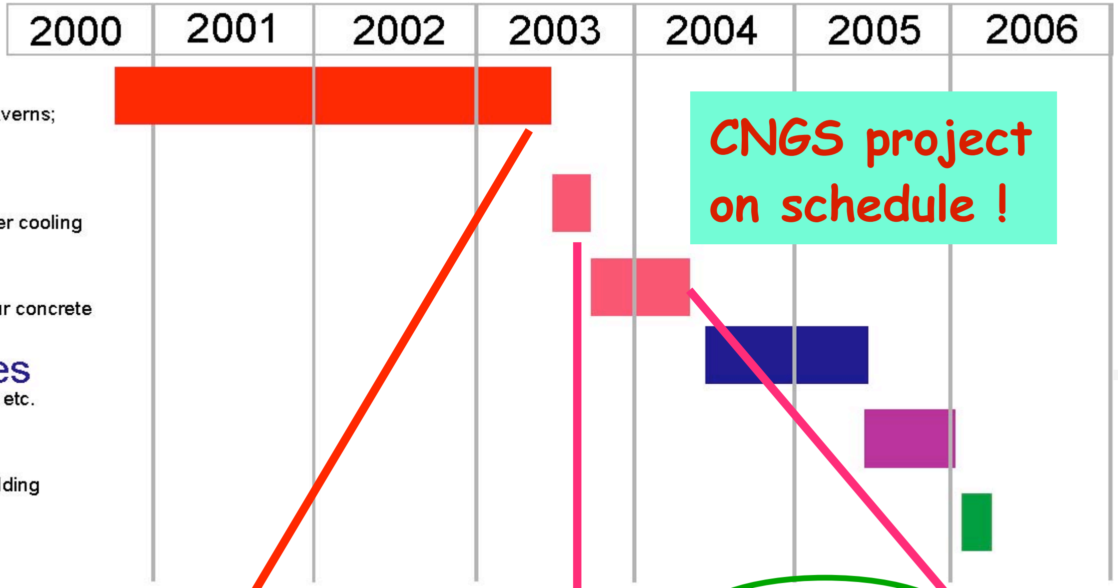
Install hadron stop
iron + graphite blocks, aluminum plate + water cooling

Install decay tube
lower decay tube sleeves, weld together, pour concrete

Install general services
electrical services, ventilation, cooling water, etc.

Install equipment
proton beam line, target, horn+reflector, shielding

Commissioning



First beam to Gran Sasso: May 2006

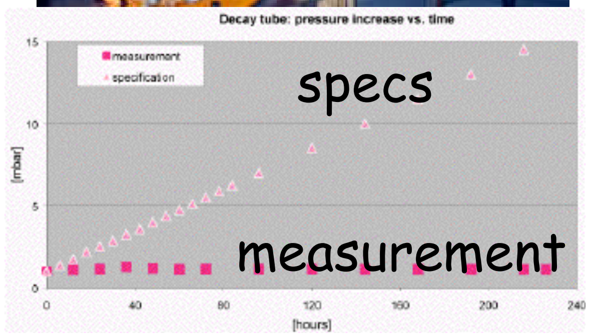
First beam in May 2006

Intensity increase (1.5) under study with dedicated machine tests

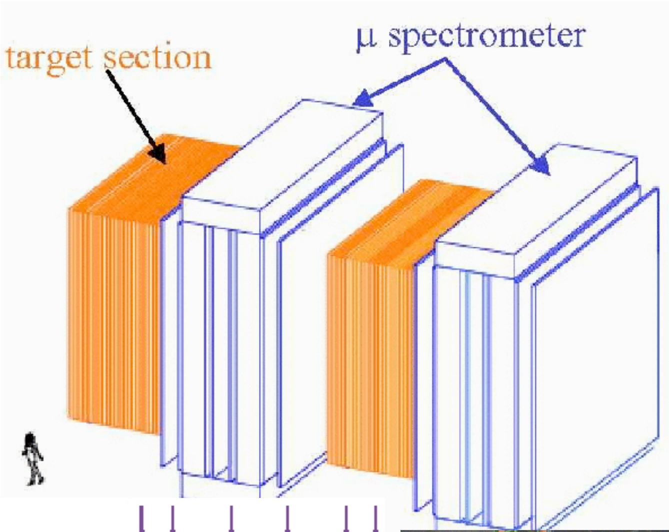
Civil engineering completed

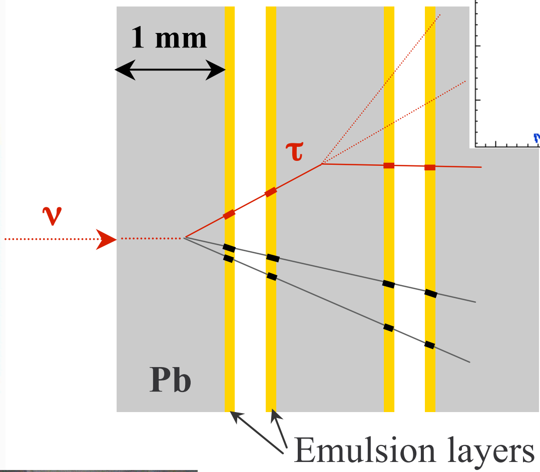
Hadron stop installed

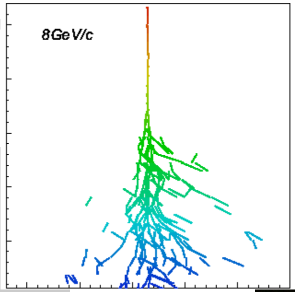
Decay tube installed and vacuum tested

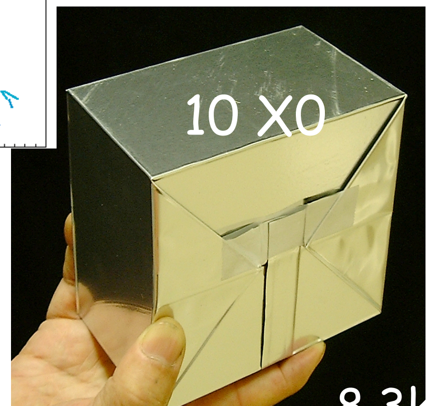


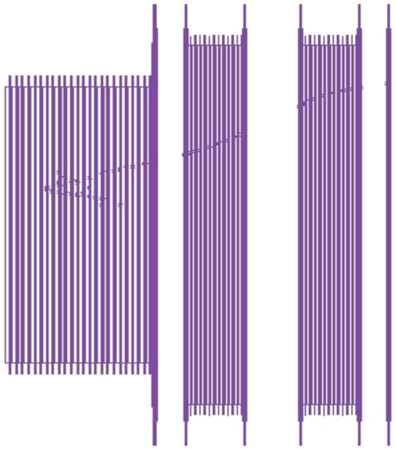
OPERA is also on schedule



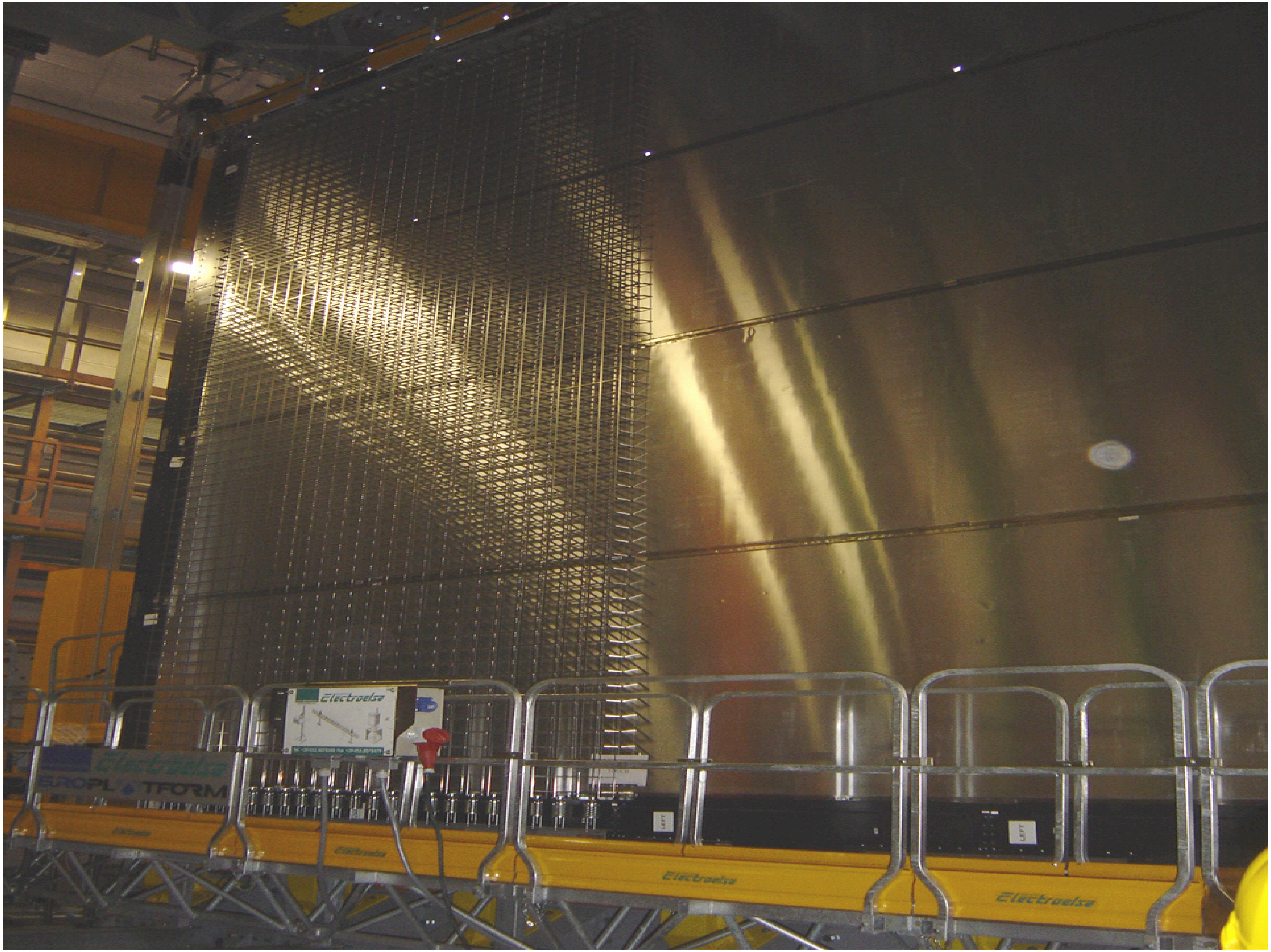








1.5/10 Million films shipped to GS


Electroelse
LEFT
LEFT
Electroelse
Electroelse

$\nu_\mu \to \nu_\tau$ ($\nu_\mu \to \nu_e$) sensitivity

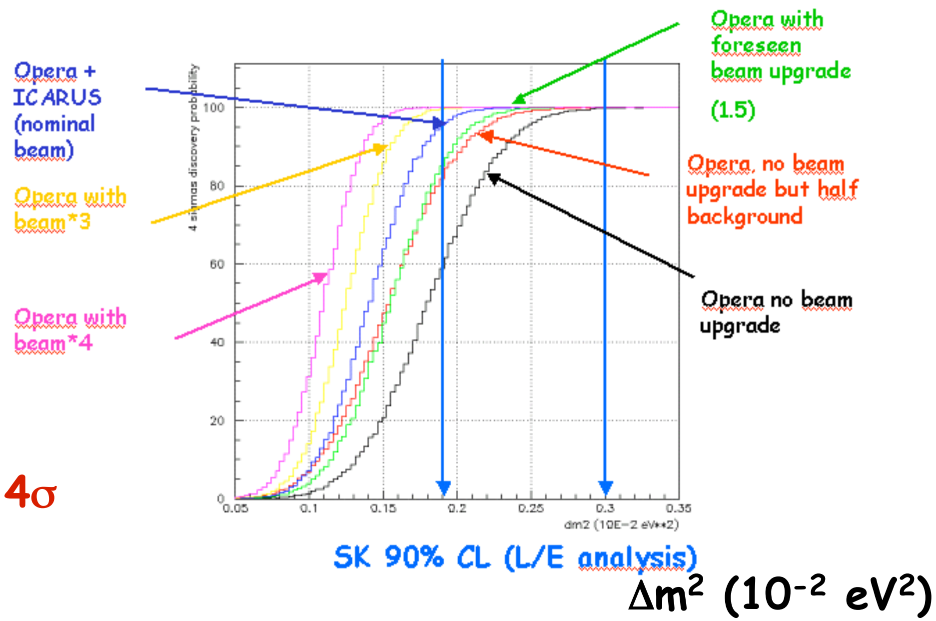
full mixing, 5 years run @ 4.5 x10^{19} pot / year

	signal (Δm^2 = 1.9 x 10^{-3} eV^2)	signal (Δm^2 = 2.4 x 10^{-3} eV^2)	signal (Δm^2 = 3.0x 10^{-3} eV^2)	BKGD
OPERA 1.8 kton fiducial	6.6(10)	10.5(15.8)	16.4(24.6)	0.7(1.06)

(...) with CNGS beam upgrade (X 1.5)

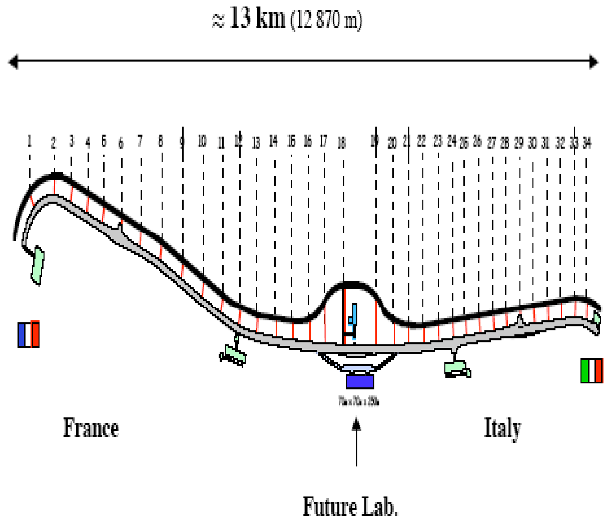
$\sin^2 2\theta_{13}$	Θ_{13}
<0.06	<7.1°
<0.05 (beam *1.5)	<6.4°

Probability of observing in 5 years a number of candidates greater than a 4σ background fluctuation



Megaton detector in Fréjus (LSM)?

- Opportunity of safety gallery
- Deep enough for supernova and solar physics, good rock no water
- Many sided physics
  - Proton decay
  - Supernova
  - Neutrino beams
  - Solar/atmospheric and Other astronomy
- Discussions between french and italian gvts about diameter of the tunnel closing to an end (currently d=5.5m).
- Another site Venaus (7000 mwe) close to the Lyon Turin TGV was proposed, but beaks the Franco-Italian symmetry
- A LOI in Villars, a group was formed in France. Work essentially on neutrino beams

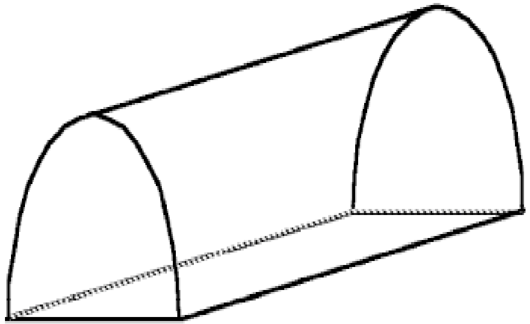


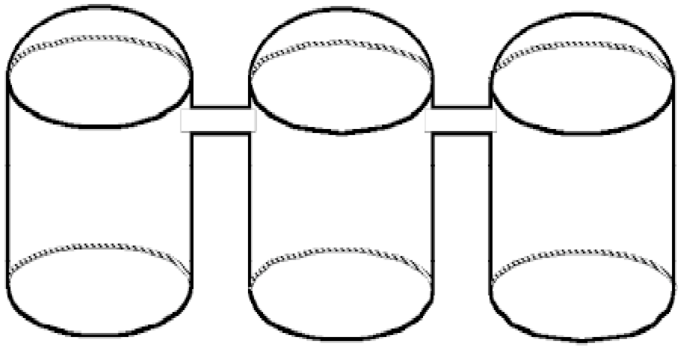
Present road Tunnel at Fréjus (grey)
and
future Tunnel (black) for safety with 34 bypasses (shelters)
connecting the two Tunnels

- A "modest" extention for a cavern 15x30m is possible at moderate cost (2MEuros)

Preliminary study
for a very large cavity ($\approx 10^6\,m^3$)
at Fréjus

Two types of geometry that will be considered
in the preliminary study for the future Lab.





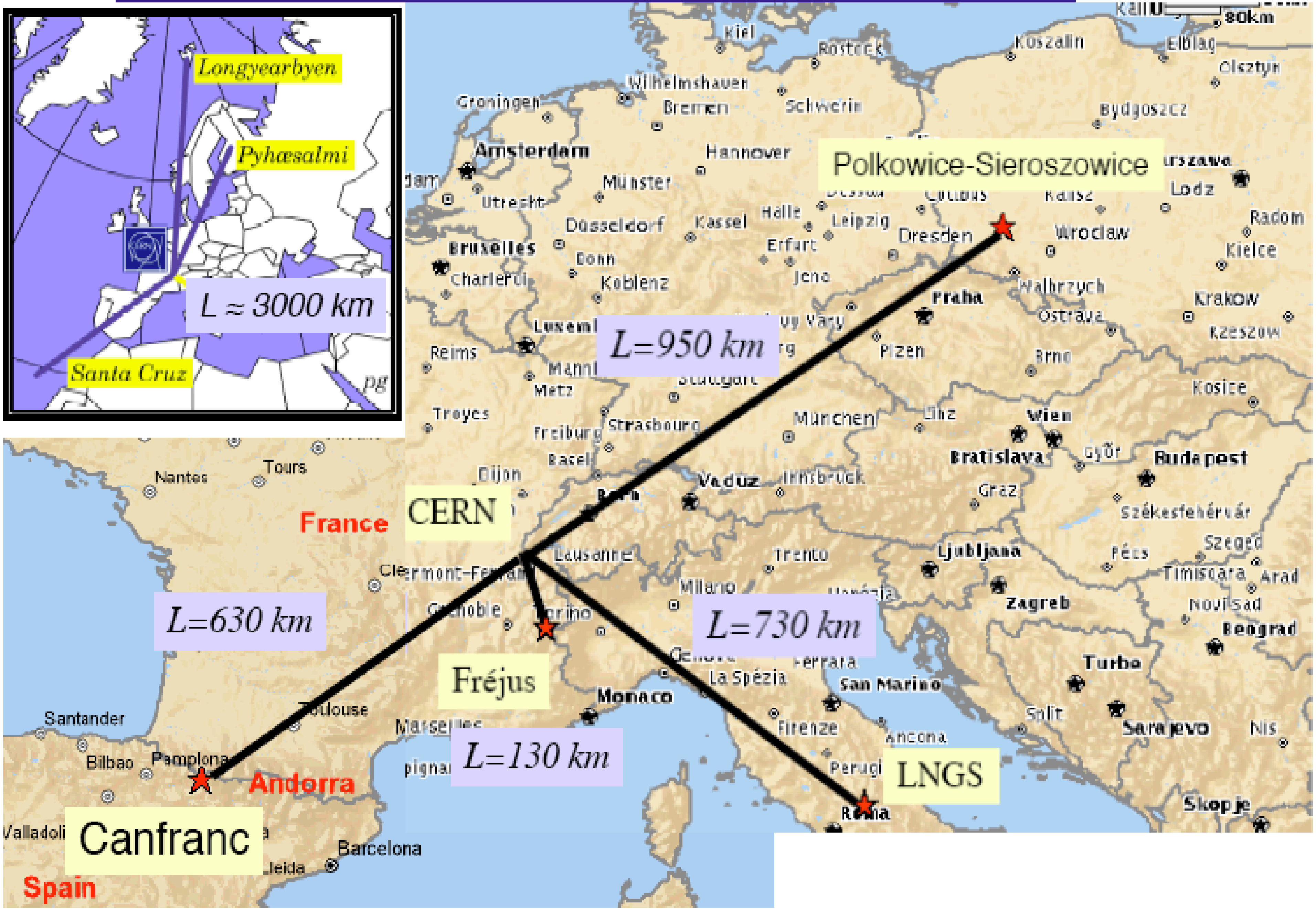
Objectives :

1) Feasibility -> determine the maximum possible size of the cavity for each type of considered geometry (see the next transparency)

2) Estimate (roughly) the cost and the time of the excavation

-> Then a more detailed ad extensive study (design study) will be performed with (hopefully) a contribution from the European Community (EC)

Possible underground sites in Europe ?



Status of neutrino mass and oscillations

Europe : CHOO reactor and in LNGS GALLEX, SAGE, MACRO

3 x 3 mixing matrix U with parameters:

θ_{12}, θ_{23} measured **θ_{13} δ (phase) unknown**

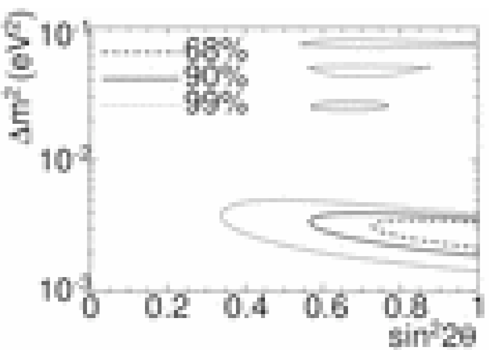
CP violation

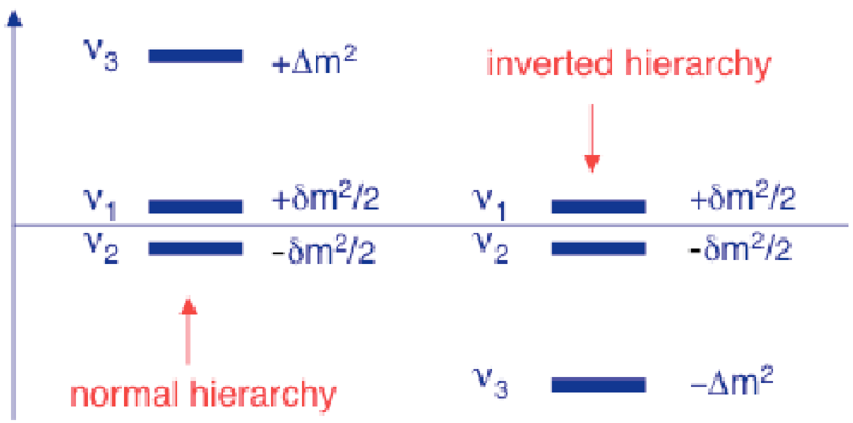
Δm^2_{12} Δm^2_{23} measured **m_ν unknown**

m_ν direct mass measurement β decay

2 β decay if Majorana neutrino

cosmological measurement



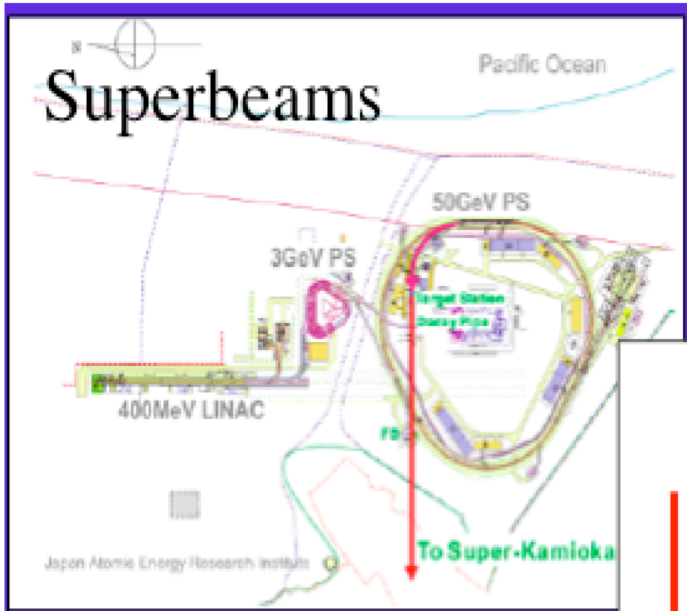


New value

Δm^2_{23} = 2.8 10^{-3} eV^2 of K2K

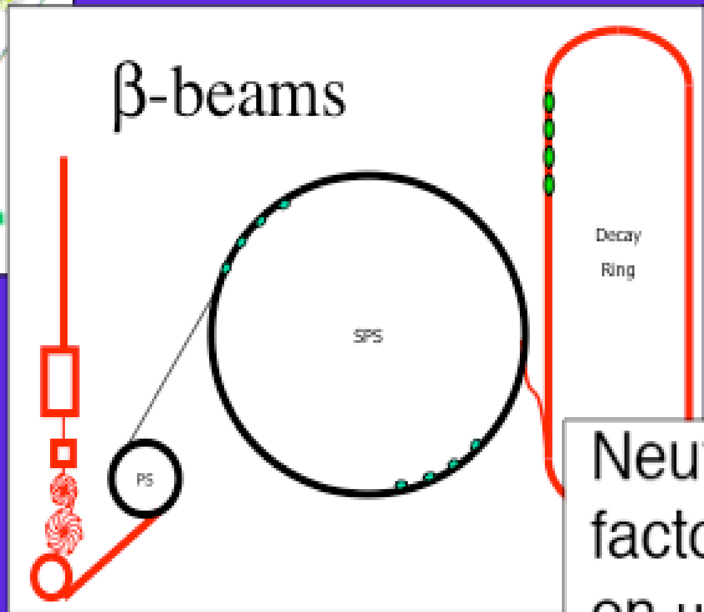
Good news for CNGS/MINOS but also Fréjus , eagerly awaiting MINOS

Future Neutrino Beams



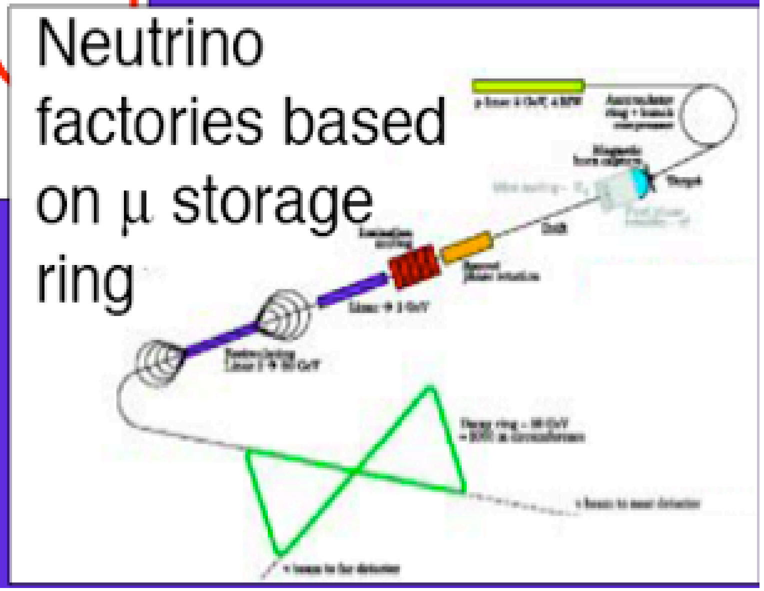
$$\pi^{\pm} \to \mu^{\pm} \overset{(-)}{\nu}_{\mu}$$

Select focusing sign



$${}^{Z}A \to {}^{Z\mp1}A \;\; \beta^{\pm} \;\; \overset{(-)}{\nu}_{e}$$

Select ion



$$\left.\begin{array}{l} \mu^{-} \to e^{-}\bar{\nu}_{e}\nu_{\mu} \\ \mu^{+} \to e^{+}\nu_{e}\bar{\nu}_{\mu} \end{array}\right\}$$

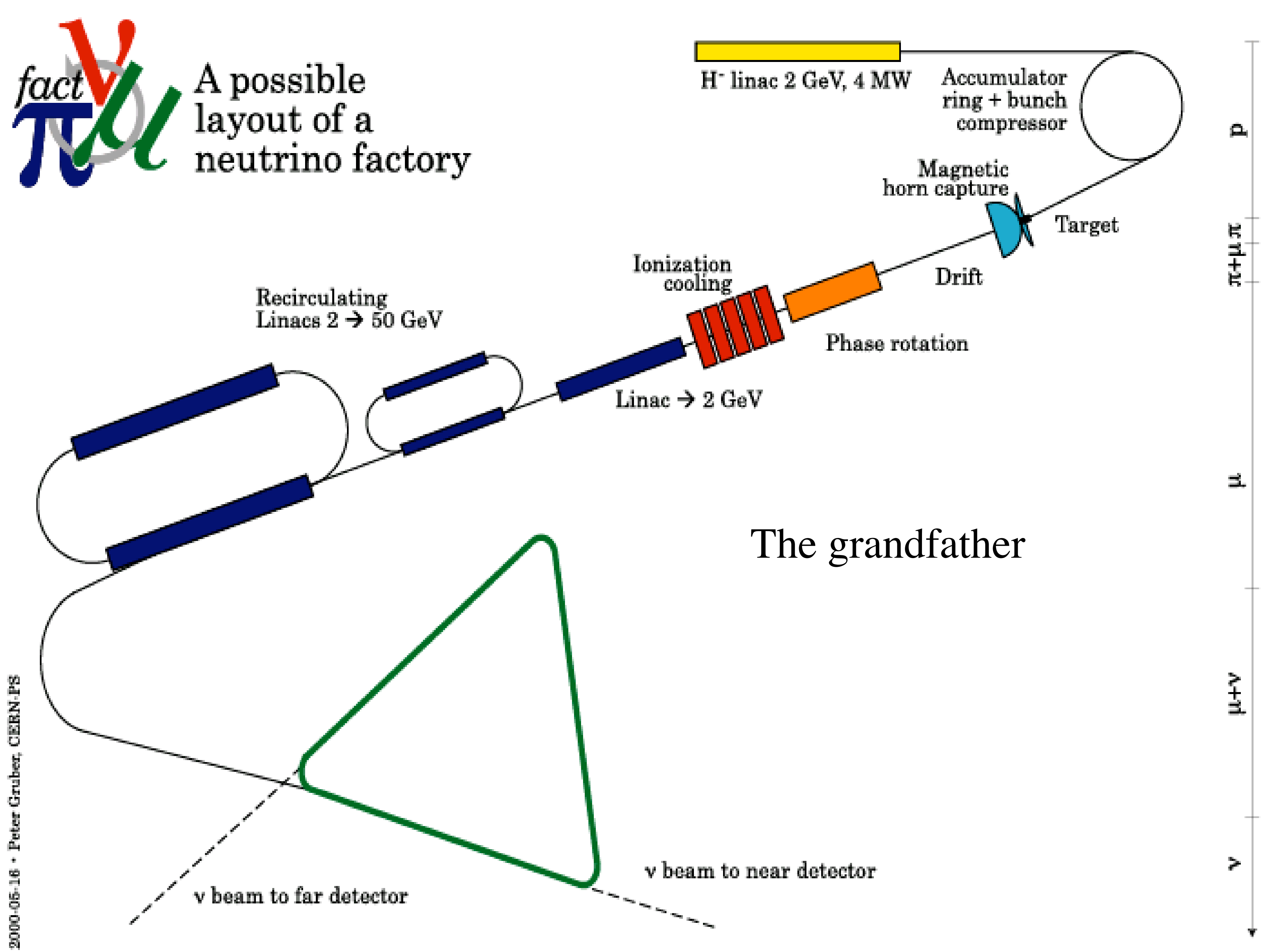
Select ring sign

Extract from the minutes of the December CERN Council

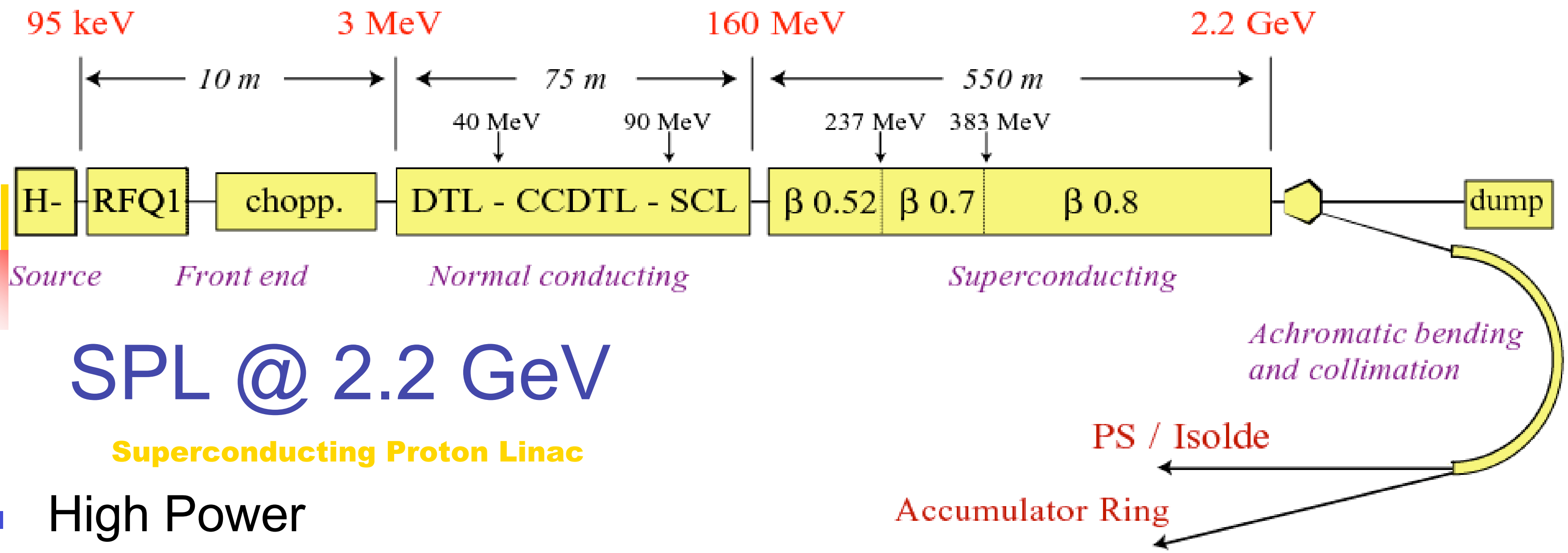
- The SPC concurred with the SPSC that future neutrino facilities offered great promise for fundamental discoveries.
- The SPC recommended that CERN should join the world effort in developing new technologies for new facilities: beta beam, neutrino factories and wherever they were sited.
- The work should focus on enabling CERN to do the best choice by 2010 in future physics programme.
- The SPC would present in June 2005 a written report to the council on the future of fixed target physics at CERN.

Elements for European/World strategy to be decided till 2010

- Superbeam/Betabeam (2015) and then Nufact (2020-25) or Nufact asap?
  - "slow" vs "fast" train
  - Proton decay and astrophysics vs dedicated measurement (explore symmetry)
- If superbeam/betabeam,
  - Megaton Cherenkov or 100 kton Liquid Argon?
  - Run at maximum of oscillation? or where synergy with astro/proton decay?
- If betabeam which gamma?
  - Low energy? (SPS) medium (Tevatron) or high energy (LHC)?
- If Neutrino factory how many sites/detectors ?
  - Iron/scintillator, Lar, OPERAplus
- If Megaton water Cherenkov
  - Standard PM (good old 20inch, cheaper) or new risky ideas (HPD, wallpaper)?
- Quid MINOS, CNGS, reactor and JPARC-I input?
- Quid decisions on ILC, upgrade LHC,ITER , KM3 etc?



The grandfather



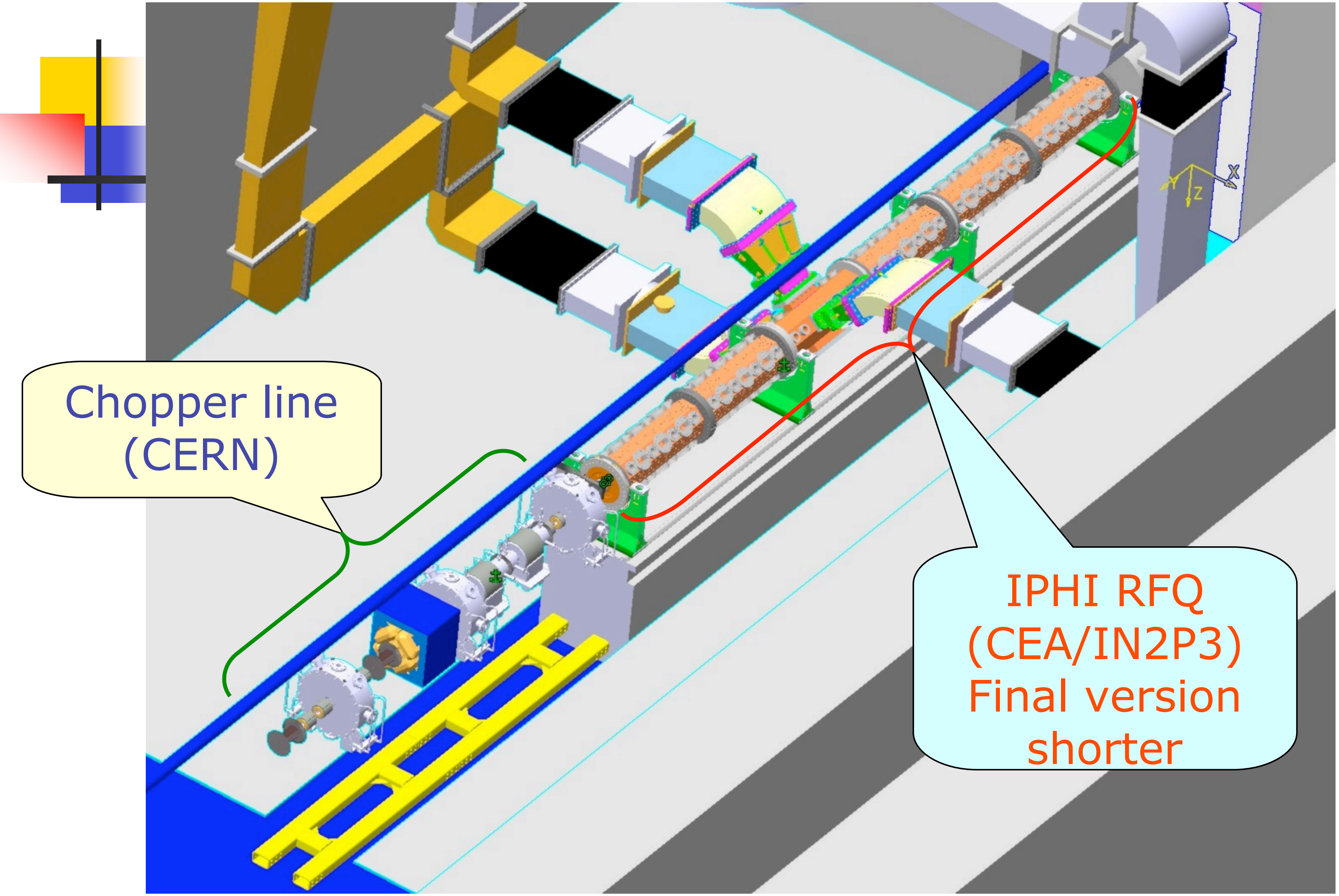
SPL @ 2.2 GeV

Superconducting Proton Linac

- High Power
  - LINAC @ 4 MW
  - Rep. Rate 50 Hz
  - 2.27 10^{14} p/pulse (1.2 ms burst with 352 MHz bunching & 44 MHz time structure)
- Accumulator and compressor ring to reduce the pulse length

- SPL also valuable for LHC luminosity upgrade and next generation radio-active ion beam facility in Europe (EURISOL)
- 160 MeV linac (“Linac 4”) justified as new PSB injector for LHC (ultimate luminosity and beyond) and ISOLDE (higher flux)
- 3 MeV pre-injector: approved

3 MeV test place – Preliminary layout

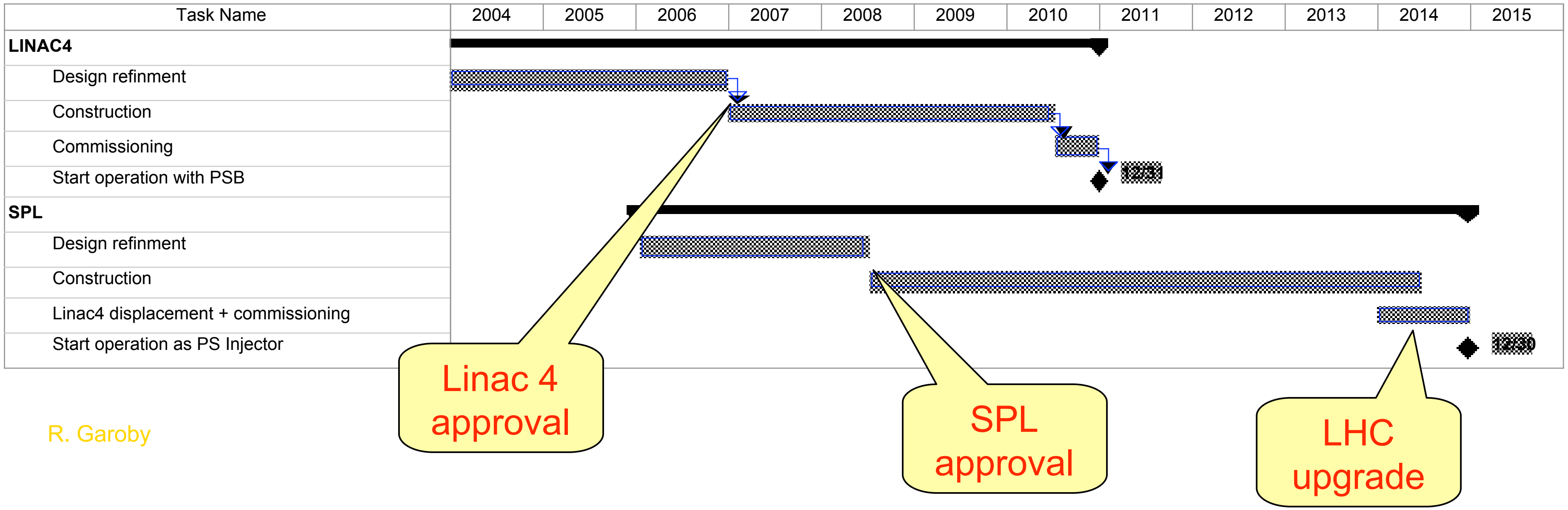


R. Garoby

SPL Proposed Roadmap

Assumptions:

- construction of Linac4 in 2007/10 *(with complementary resources, before end of LHC payment)*
- construction of SPL in 2008/15 *(after end of LHC payments)*



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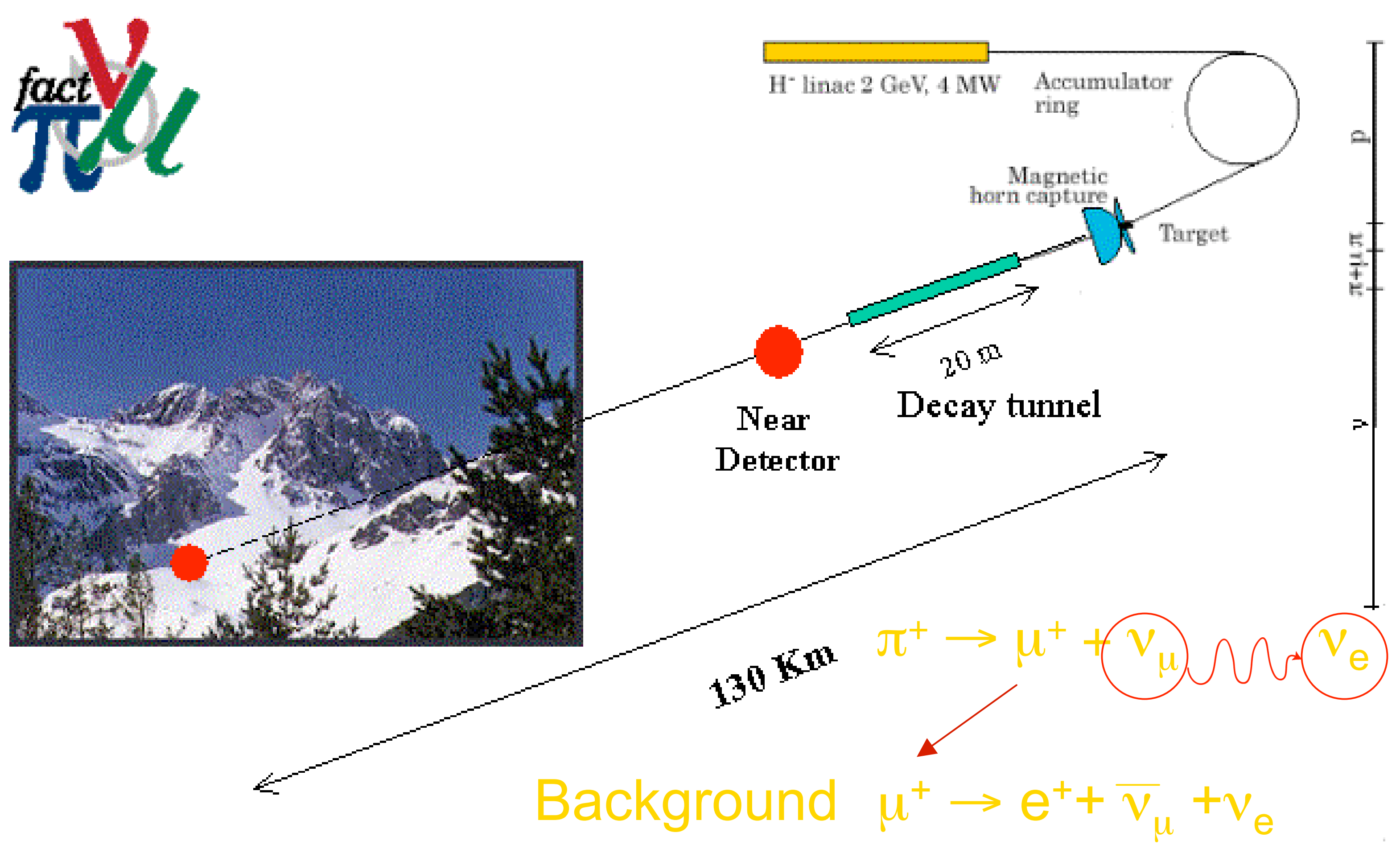
Protons from the SPL ready in 2015

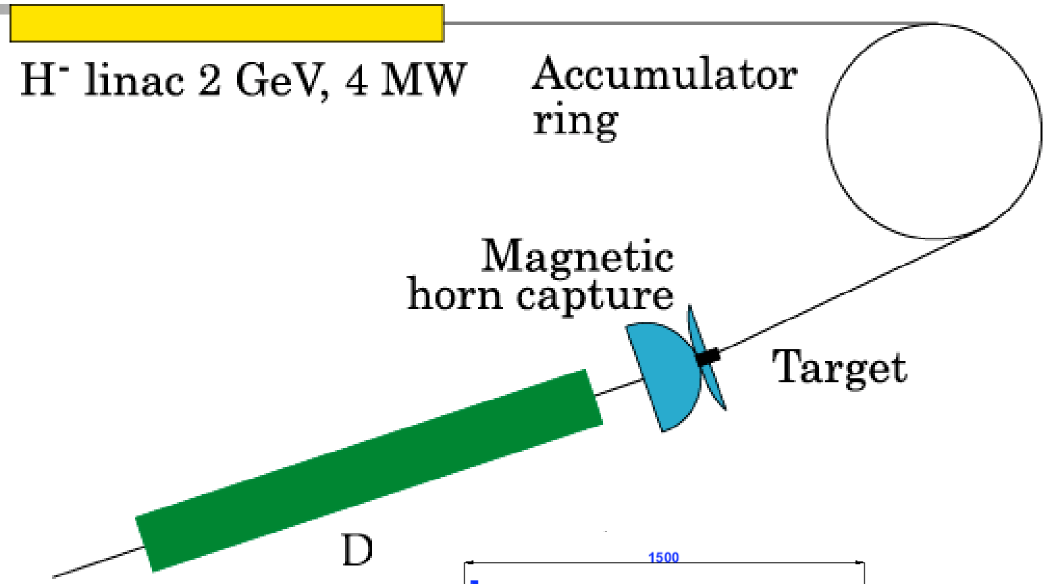
Proposal for a CERN - Super Beam to Fréjus

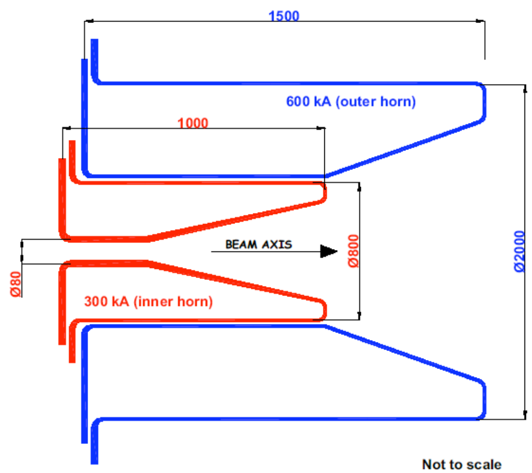


A possible layout of a Low Energy Neutrino Super Beam

Nominal set of SuperBeam parameters

- Proton beam
  - 2.2 GeV
  - 4 MW
  - 50 Hz rep. rate
- Accumulator ring
- Mercury target
- Horn focusing
  - First horn 300 kA
  - Reflector 600 kA
- Low energy pion beam: ≈ 500 MeV
  - proton energy below kaon threshold
  - Short decay channel < 100 m
- Low energy neutrino beam: ≈ 250 MeV





•Beta-beam proposal by Piero Zucchelli (2002)

Collect, focus and accelerate the neutrino parents at a given energy. This is impossible within the pion lifetime, but can be tempted within the muon lifetime (**Neutrino Factories**) or within some radioactive ion lifetime (**Beta Beams**):

- Just one flavour in the beam
- Energy shape defined by just two parameters: the endpoint energy of the beta decay and the γ of the parent ion.
- Flux normalization given by the number of ions circulating in the decay ring.
- Beam divergence given by γ.

The full ^{6}He flux MonteCarlo code

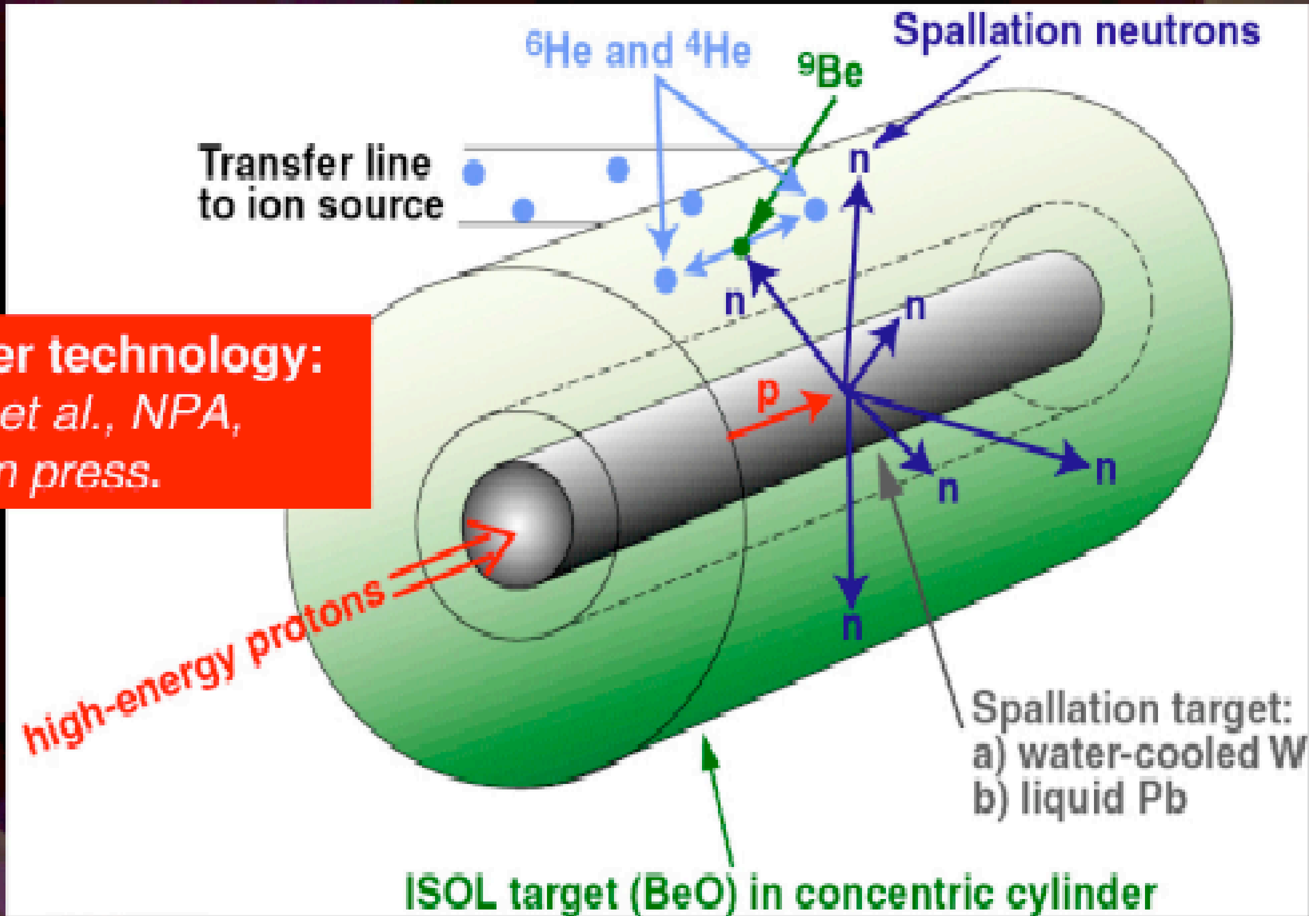
```
Function Flux(E)
Data Endp/3.5078/
Data Decays /2.9E18/

ye=me/EndP
c ...For ge(ye) see hep-ph0312068
ge=0.0300615
2gE0=2*gamma*EndP
c ...  Kinematical Limits
If(E.gt.(1-ye)*2gE0)THEN
   Flux=0.
   Return
Endif
c ...Here is the Flux
Flux=Decays*gamma**2/(pi*L**2*ge)*(E**2*(2gE0-E))/
+ 2gE0**4*Sqrt((1-E/2gE0)**2-ye**2)

Return
```

•The baseline scenario (use the SPS)

- –Avoid anything that requires a “technology jump” which
- – would cost time and money (and be risky).
- –Make maximum use of the existing infrastructure.

^{6}He production by ^{9}Be(n,α)

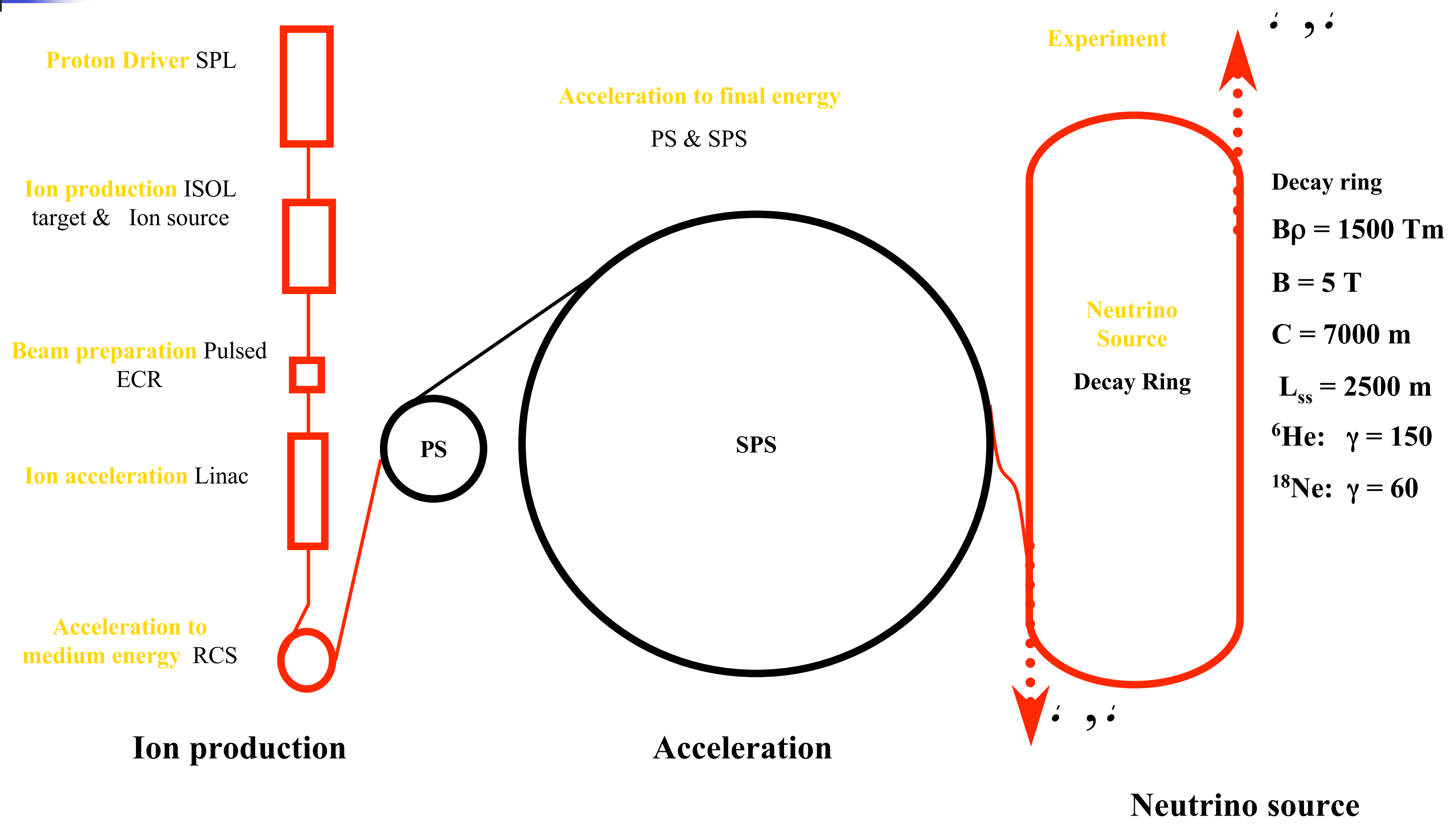
Converter technology:
J. Nolen et al., NPA, RNB-5, in press.

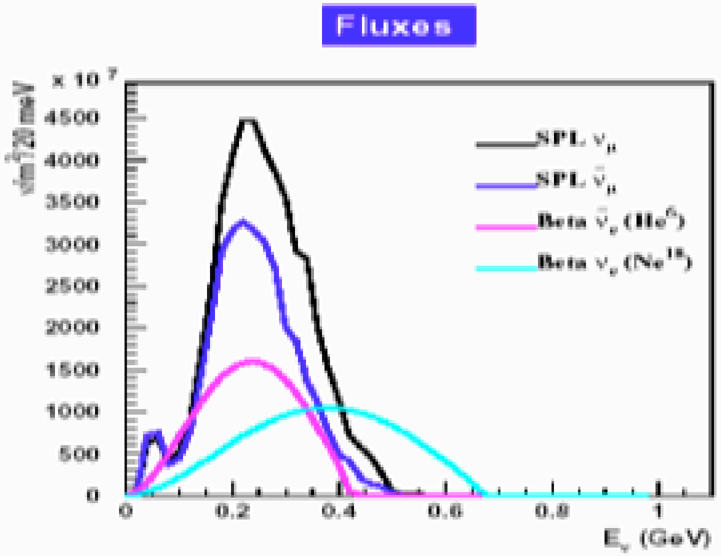


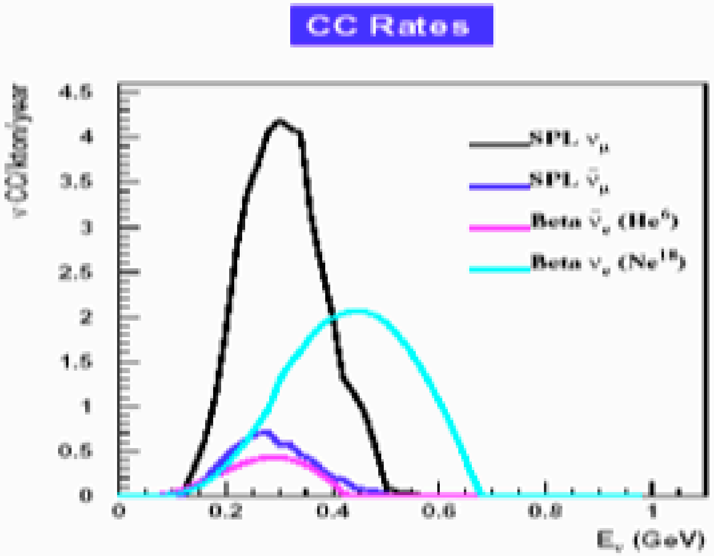
Layout very similar to planned EURISOL converter target aiming for 10^{15} fissions per s.

U. Köster, EP-ISOLDE

Beta-beam baseline design







	Fluxes @ 130 km $\nu/m^2/yr$	$< E_\nu >$ (GeV)	CC rate (no osc) events/kton/yr	$< E_\nu >$ (GeV)	Years	Integrated events (440 kton $\times$ 10 years)
SPL Super Beam						
ν_μ	$4.78 \cdot 10^{11}$	0.27	41.7	0.32	2	36698
$\overline{\nu}_\mu$	$3.33 \cdot 10^{11}$	0.25	6.6	0.30	8	23320
Beta Beam						
$\overline{\nu}_e$ ($\gamma = 60$)	$1.97 \cdot 10^{11}$	0.24	4.5	0.28	10	19709
ν_e ($\gamma = 100$)	$1.88 \cdot 10^{11}$	0.36	32.9	0.43	10	144783

$\delta m^2_{12} = 7 \cdot 10^{-5}\ eV^2$, $\theta_{13} = 1°$, $\delta_{CP} = \pi/2$, sign(Δm^2) = +1

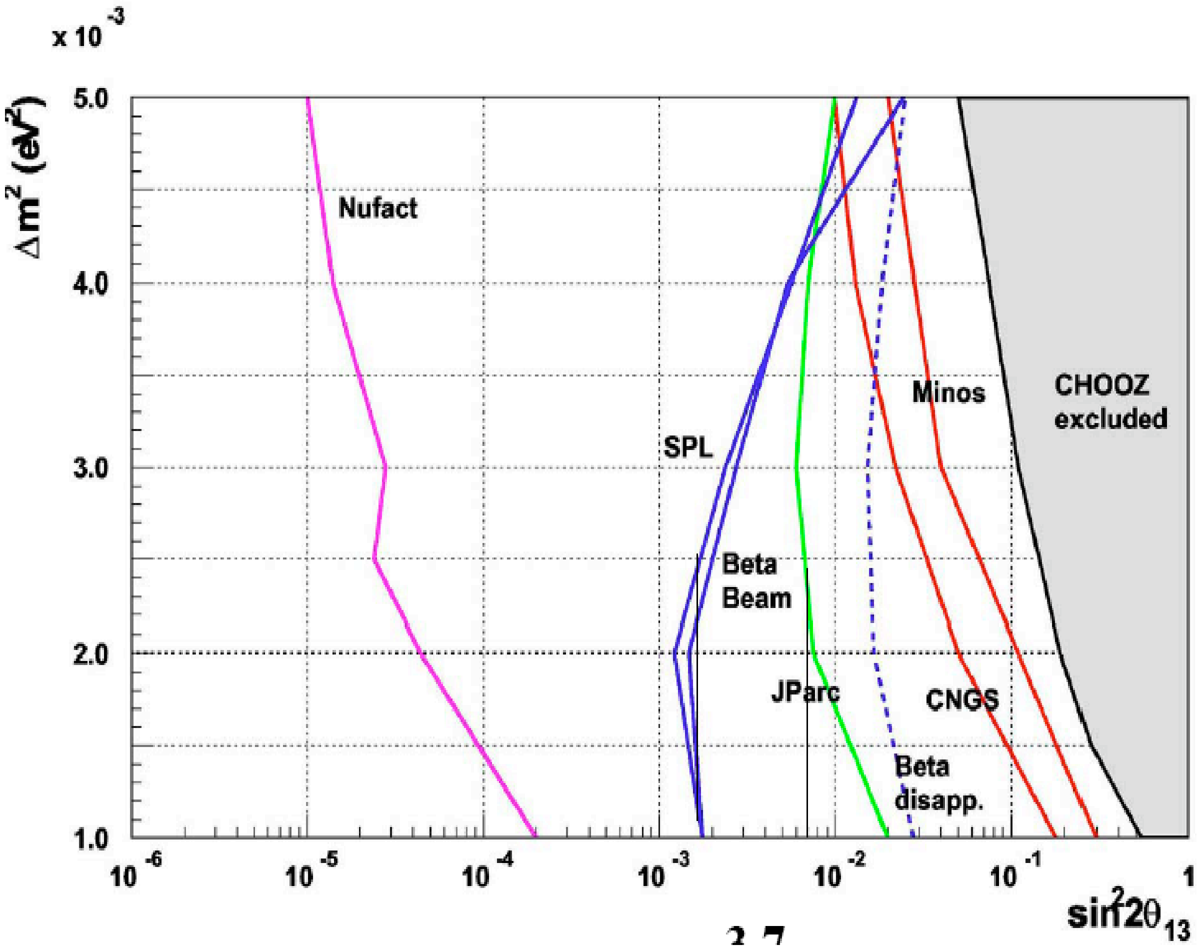
	Beta Beam		SPL-SB	
	^6He ($\gamma = 60$)	^{18}Ne ($\gamma = 100$)	ν_μ (2 yrs)	$\overline{\nu}_\mu$ (8 yrs)
CC events (no osc, no cut)	19710	144784	36698	23320
Oscillated at the Chooz limit	681	5304	1491	1182
Oscillated	1	118	2	34
δ oscillated	-12	54	-27	16
Beam background	0	0	140	101
Detector backgrounds	1	397	37	50

δ-oscillated events indicates the difference between the oscillated events computed with $\delta = 90°$ and with $\delta = 0$.

Problems of low energy:

- Fermi motion makes difficult the use of energy bins, only counting
- Uncertainties for the cross sections
- Atmospheric backgrounds

Nominal settings sensitivity



The gamma factor to be "on-peak"...

$$E^{osc}_{\max} \approx \frac{E_{\max}}{2} = \frac{2\gamma_{opt} Q_\beta}{2} \Rightarrow \gamma_{opt} \approx \frac{E^{osc}_{\max}}{Q_\beta} = \frac{2 \times 1.27 \Delta m^2 L}{\pi Q_\beta}$$

CERN-Fréjus:

L=130 km		Δm^2 (eV^2)			
Nucleus	Q_β (MeV)	1.5x10^{-3} 160 MeV	2x10^{-3} 210 MeV	2.5x10^{-3} 260 MeV	3x10^{-3} 315 MeV
^{6}He	3.5	45 (135 GeV)	60 (180 GeV)	75 (225 GeV)	90 (270 GeV)
^{18}Ne	3.4	46 (85 GeV)	62 (110 GeV)	77 (140 GeV)	93 (170 GeV)

CERN-somewhere:

L=300 km		Δm^2 (eV^2)			
Nucleus	Q_β (MeV)	1.5x10^{-3} 360 MeV	2x10^{-3} 485 MeV	2.5x10^{-3} 610 MeV	3x10^{-3} 730 MeV
^{6}He	3.5	104 (310 GeV)	139 (415 GeV)	173 (520 GeV)	208 (620 GeV)
^{18}Ne	3.4	107 (190 GeV)	143 (250 GeV)	178 (320 GeV)	214 (385 GeV)

CERN-Canfranc:

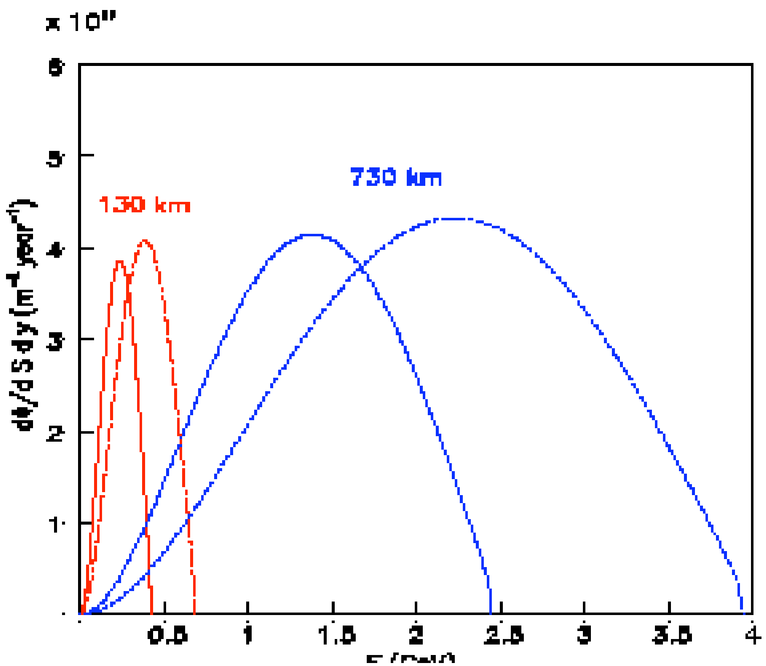
L=630 km		Δm^2 (eV^2)			
Nucleus	Q_β (MeV)	1.5x10^{-3} 760 MeV	2x10^{-3} 1 GeV	2.5x10^{-3} 1.3 GeV	3x10^{-3} 1.5 GeV
^{6}He	3.5	218 (650 GeV)	291 (870 GeV)	364 (1.1 TeV)	437 (1.3 TeV)
^{18}Ne	3.4	225 (400 GeV)	300 (540 GeV)	375 (670 GeV)	449 (800 GeV)

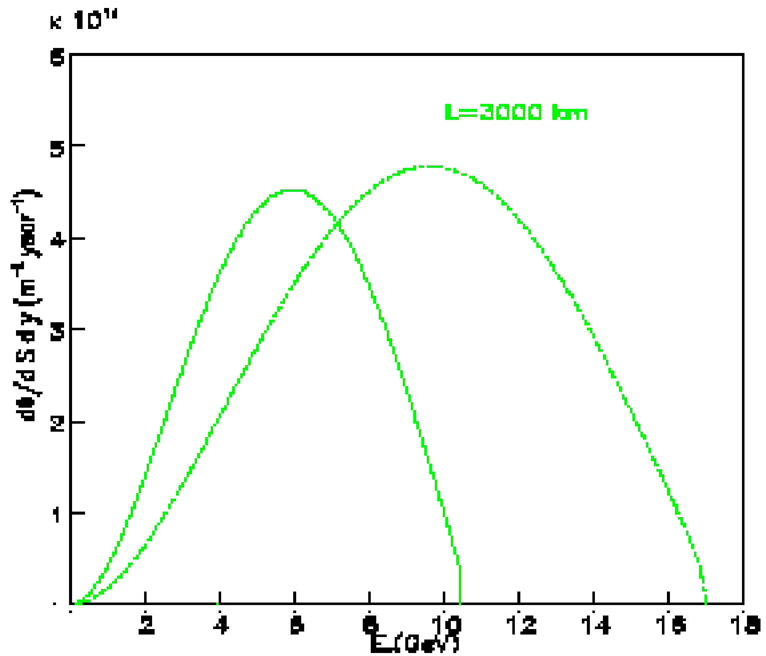
CERN-Sierozowice (Poland):

L=950 km		Δm^2 (eV^2)			
Nucleus	Q_β (MeV)	1.5x10^{-3} 1.2 GeV	2x10^{-3} 1.5 GeV	2.5x10^{-3} 1.9 GeV	3x10^{-3} 2.3 GeV
^{6}He	3.5	329 (1 TeV)	439 (1.3 TeV)	549 (1.6 TeV)	658 (2 TeV)
^{18}Ne	3.4	339 (610 GeV)	452 (810 GeV)	565 (1 TeV)	678 (1.2 TeV)

Higher-gamma Beta Beam example

γ	$L(km)$	$\bar{\nu}_e$ CC (KTon y)	ν_e CC (KTon y)	$\langle E_\nu \rangle (GeV)$
60/100	130	4.7	32.8	0.23/0.37
350/580	730	57.5	224.7	1.35/2.18
1500/2500	3000	282.7	993.1	5.80/9.39

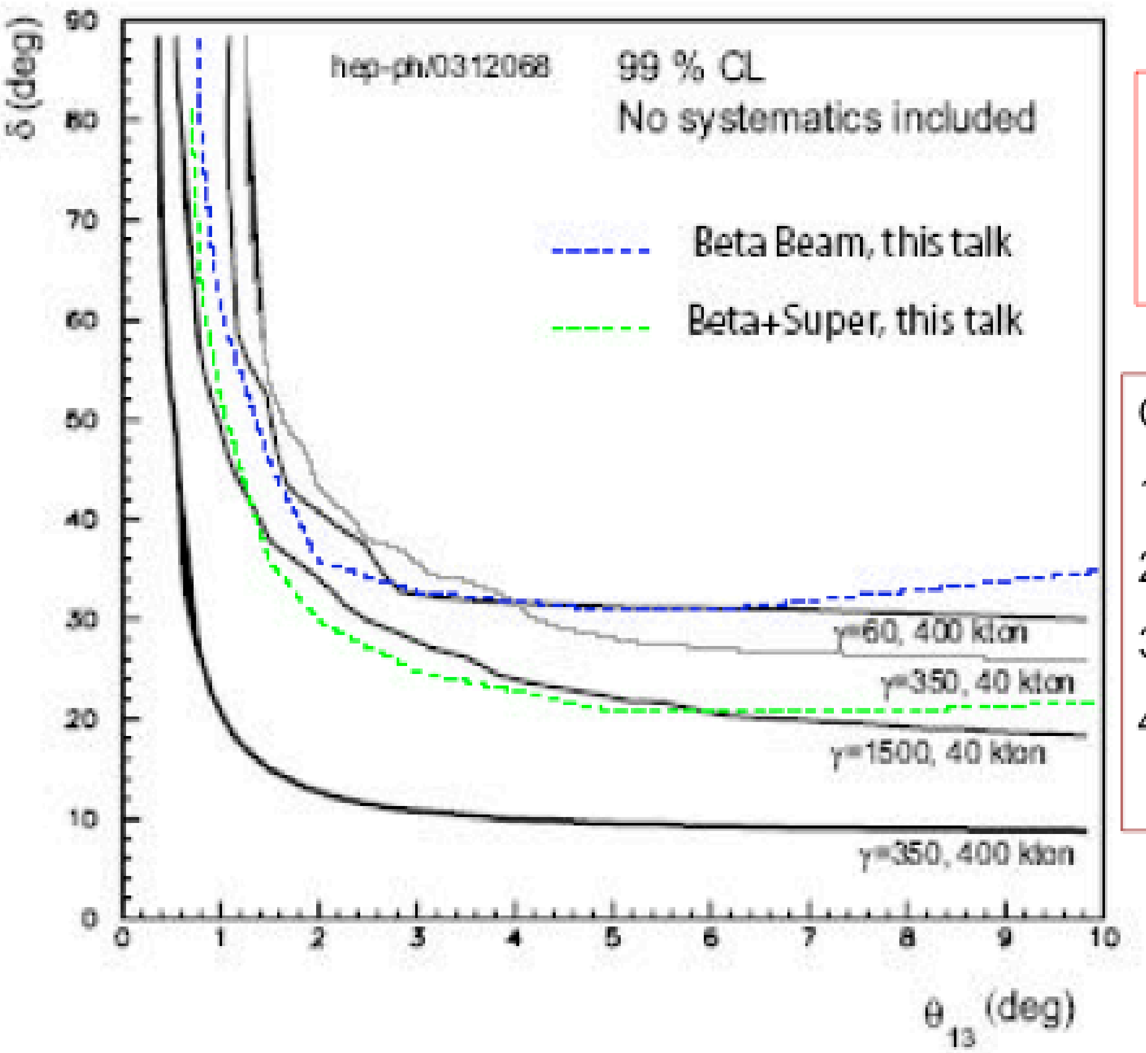




P. Hernández

HIGH ENERGY BETA BEAMS (I) (J.Burguet-Castell)

P. Hernandez, J.J. Gomez-Cadenas et al., hep-ph/0312068



1. beta beam standard
2. γ =350, 732 km, 400kT
3. γ =1500, 3000 km,40 kT

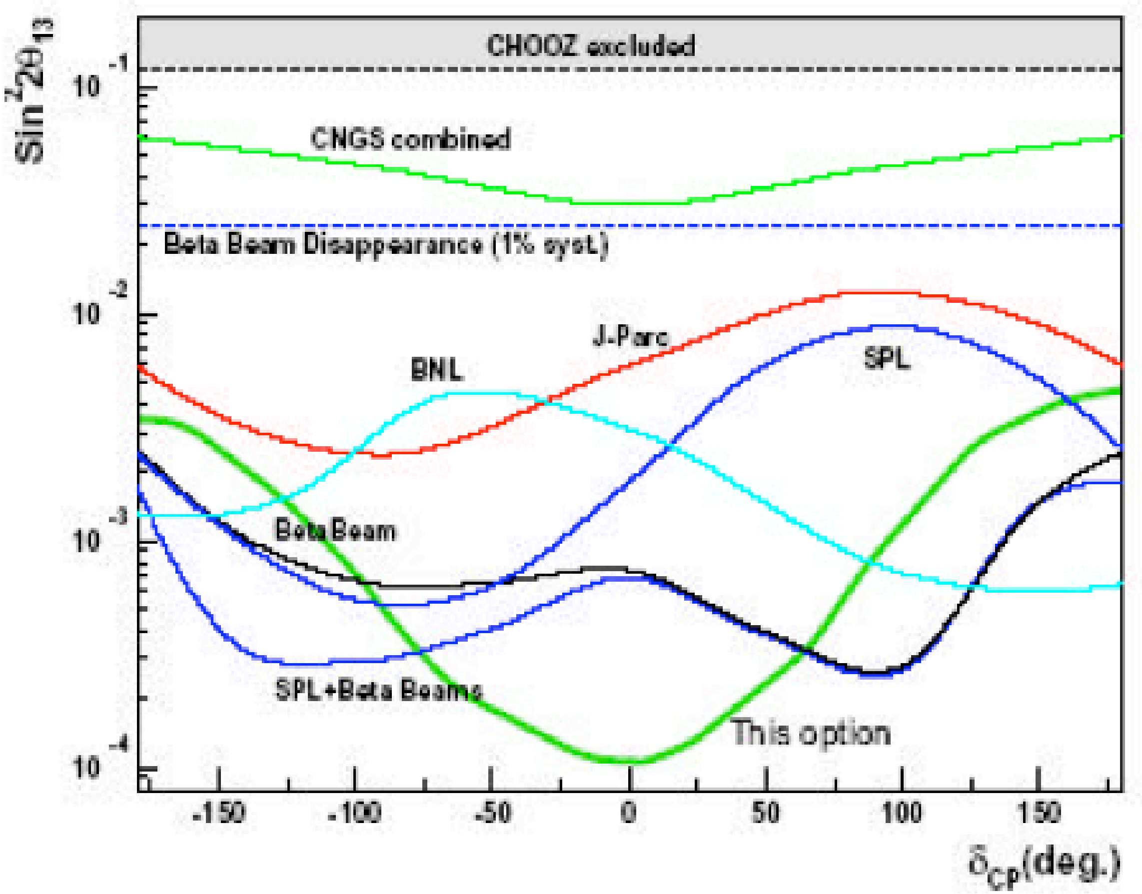
Questions:

1. Is the same flux realistic?
2. 400 kT at GS?
3. Price of decay ring
4. Schedule? (Tevatron)

Medium

HIGH ENERGY BETA BEAMS (II) (P. Migliozzi)

P. Migliozzi, F. Terranova et al., hep-ph/0405081



γ = 2500 (LHC)

cheap detector (muon counting) installed at Gran Sasso

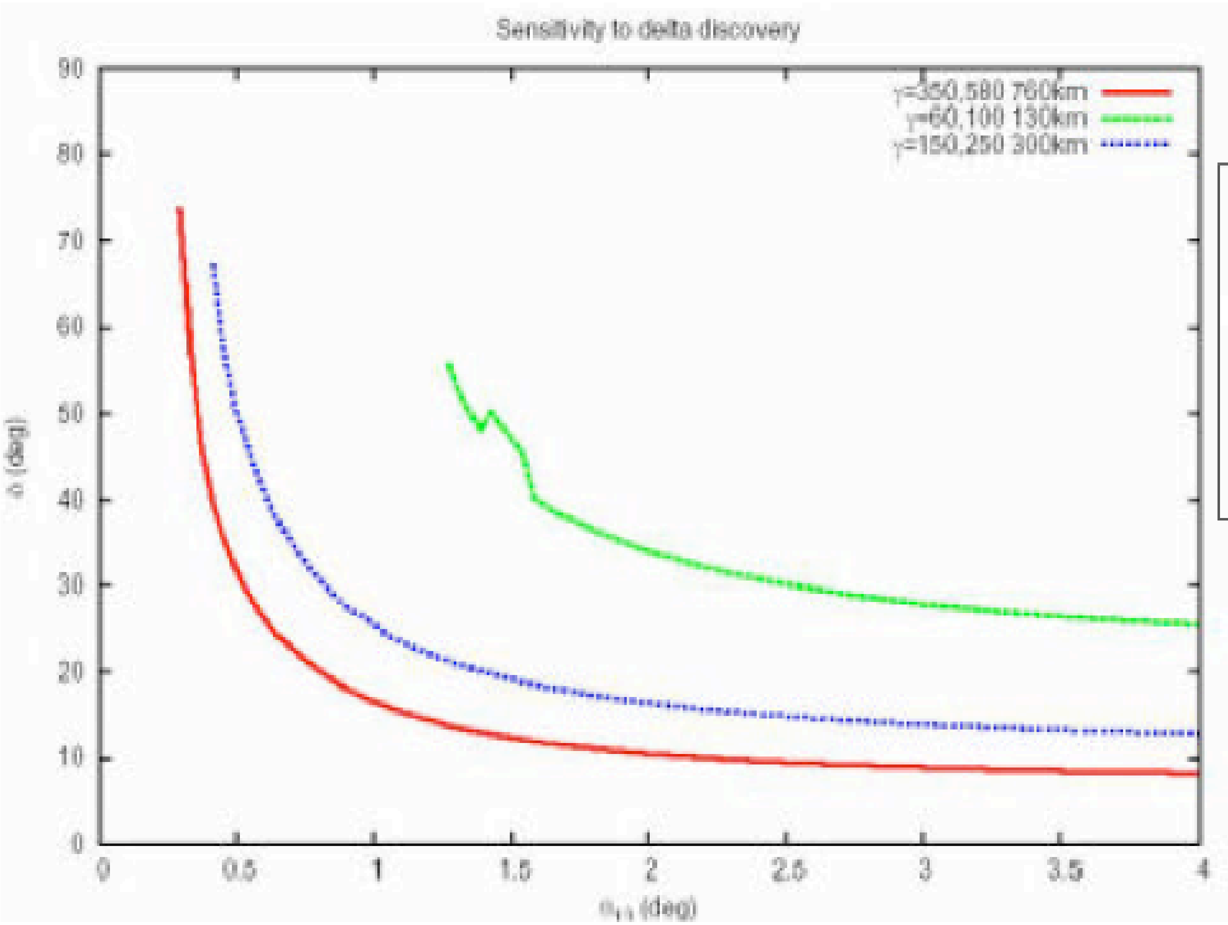
Question:

Flux ????

High to LNGS

HIGH ENERGY BETA BEAMS (III) (J.J. Gomez-Cadenas at NOW04)

Us the highest SPS energy



Baseline scenario

Tevatron option

SPS option, 300 km, γ =150/250

Remarks:

Baseline 3 σ before optimization

other 99% with no systematics

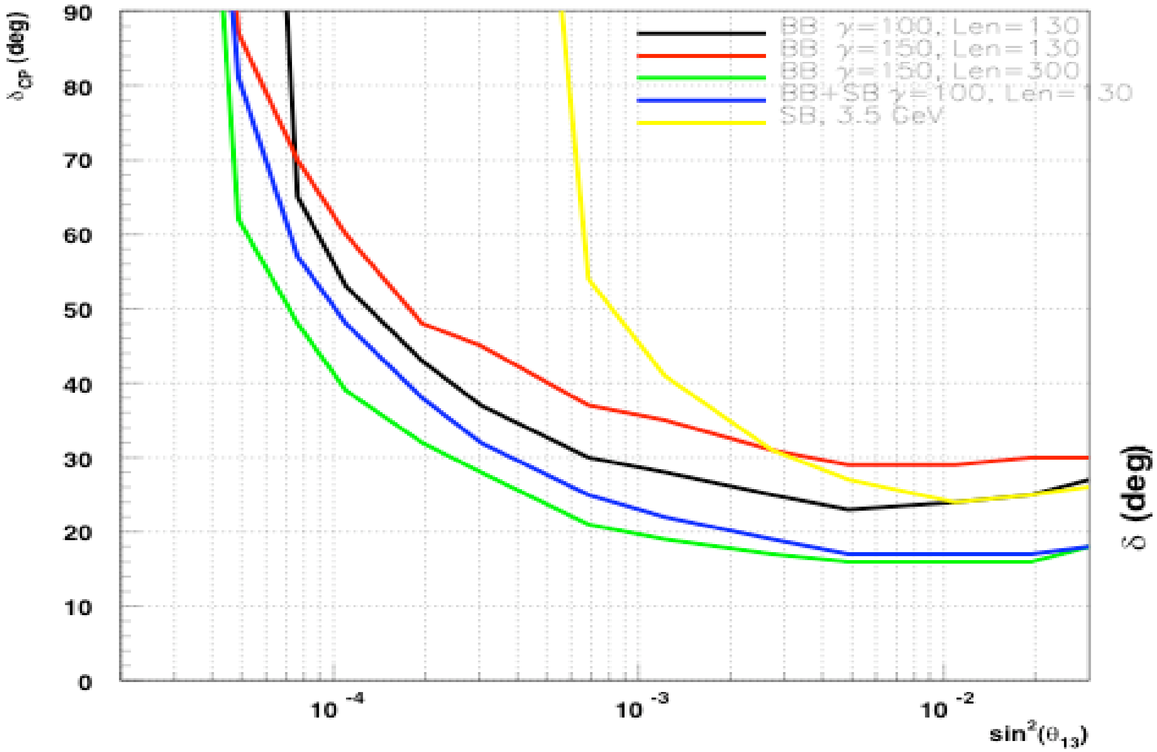
Questions:

Where?

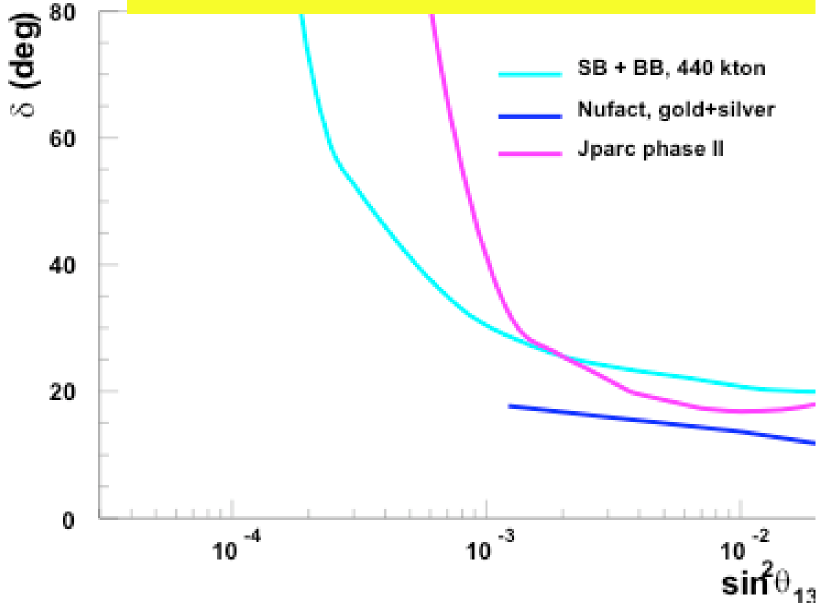
When?

It is not necessary to run on the oscillation maximum

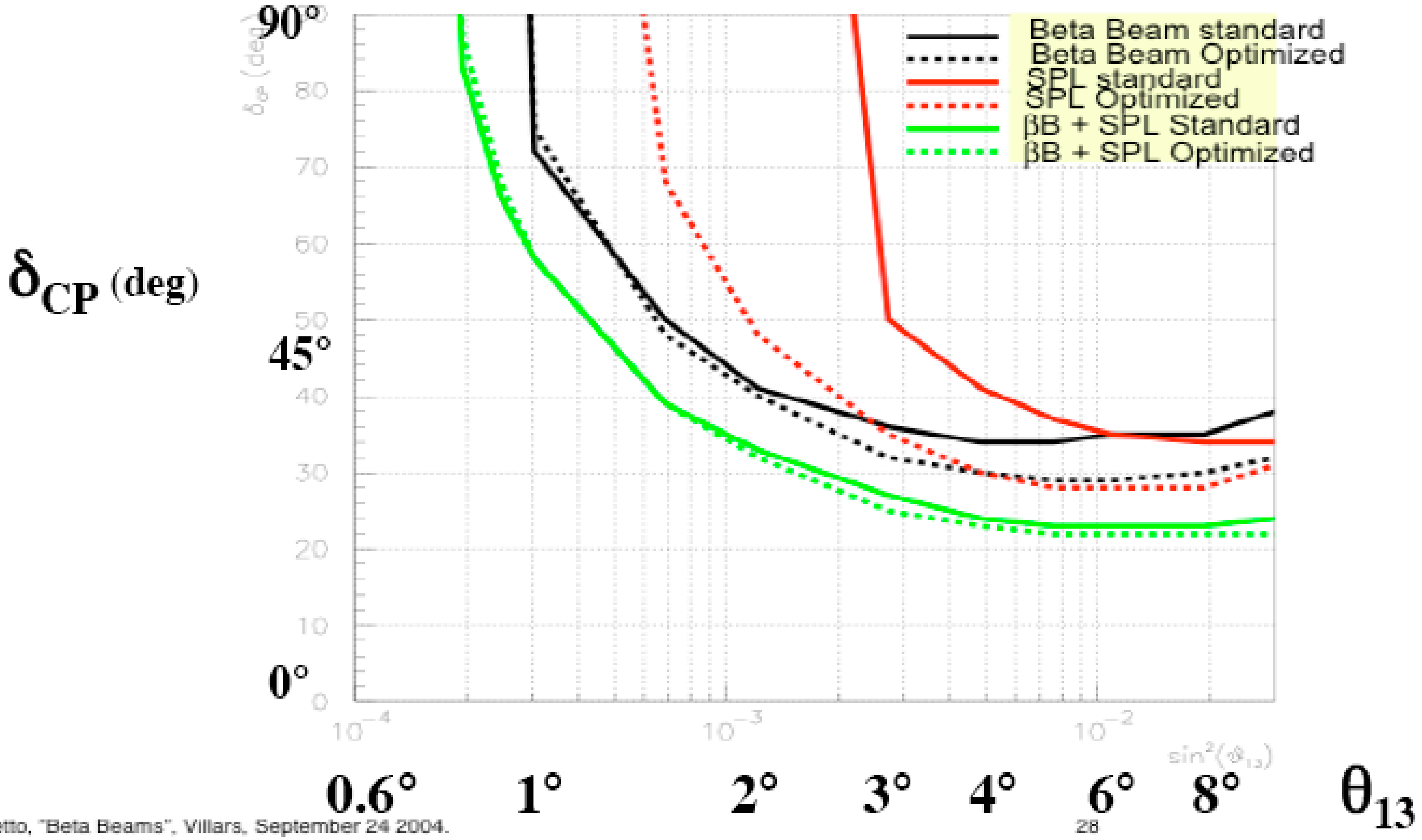
Higher gamma, Energy bins



Old settings Counting only



SPL at 2.2 GeV is also not optimised, 3.5 GeV is better (Cazes et al)



A strategy for future application of the liquid Argon TPC

- **A 100 ton detector in a near-site of a long-baseline facility** is a straight forward and very desirable application of the technique. This is a mandatory step in order to be able to handle high statistics provided by large detectors. Detector will be a powerful tool for ultimate systematic errors in oscillation parameter determination.

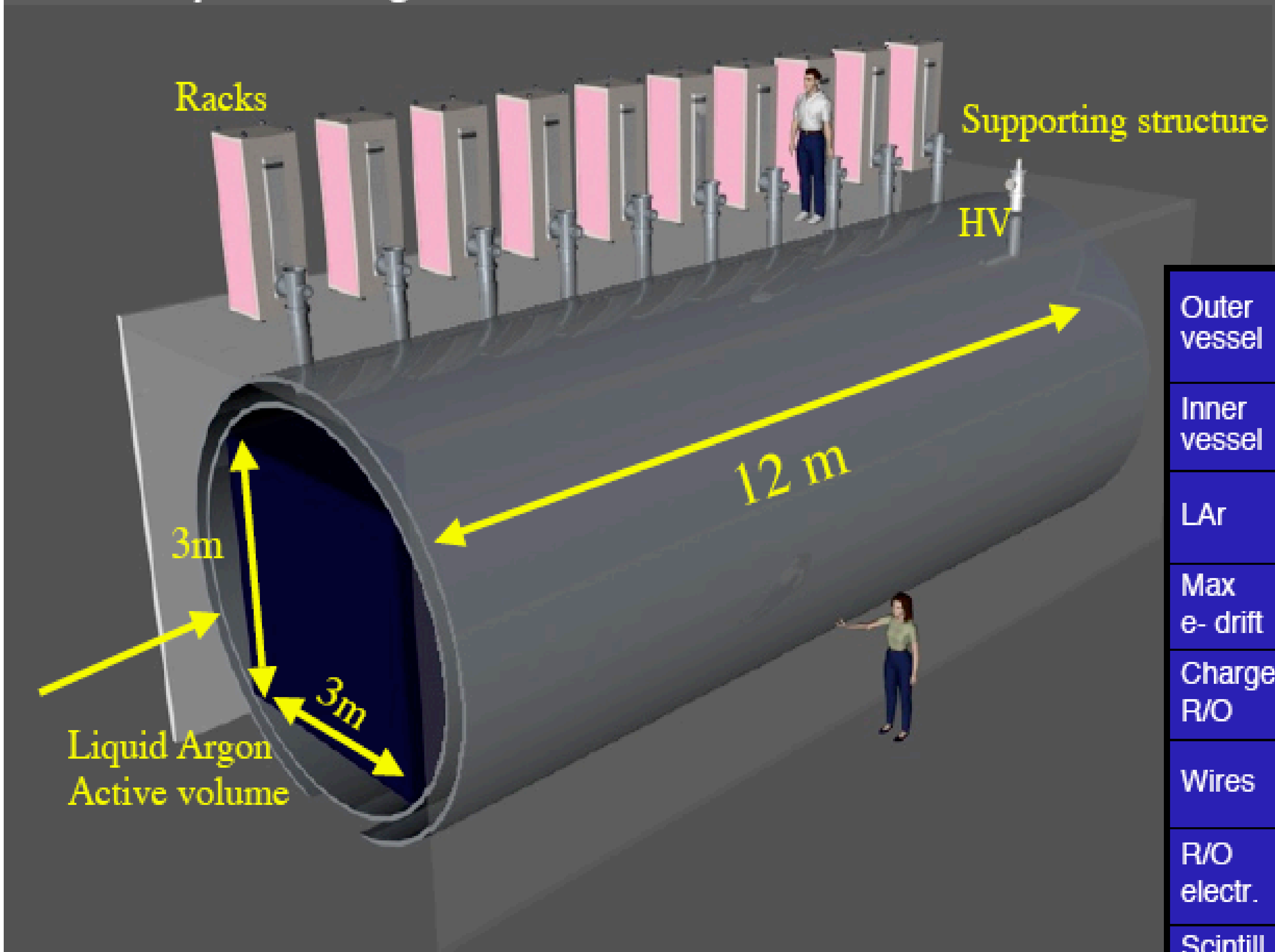
- **A 100 kton liquid Argon TPC** will deliver extraordinary physics output. It will be an ideal match for a Phase-II Superbeam, Betabeam or Neutrino Factory. This program is very challenging. Tentative design and preliminary costing of such a detector are available, as shown later. R&D is in progress.
- **A 10% full-scale prototype** on the scale of 10 kton could be readily envisaged as an engineering design test with a physics program of its own. This step could be detached from a neutrino facility. This phase is relatively mature.
- **An open issue is the necessity of a magnetic field encompassing the liquid Argon volume.**

This strategy assumes a graded evolution of the international neutrino physics program within the next few decades.

If a potential window of opportunity is positively reviewed with proper timescale, then one could envisage a prompter LOI-phase for the 100 kton.

A. Rubbia

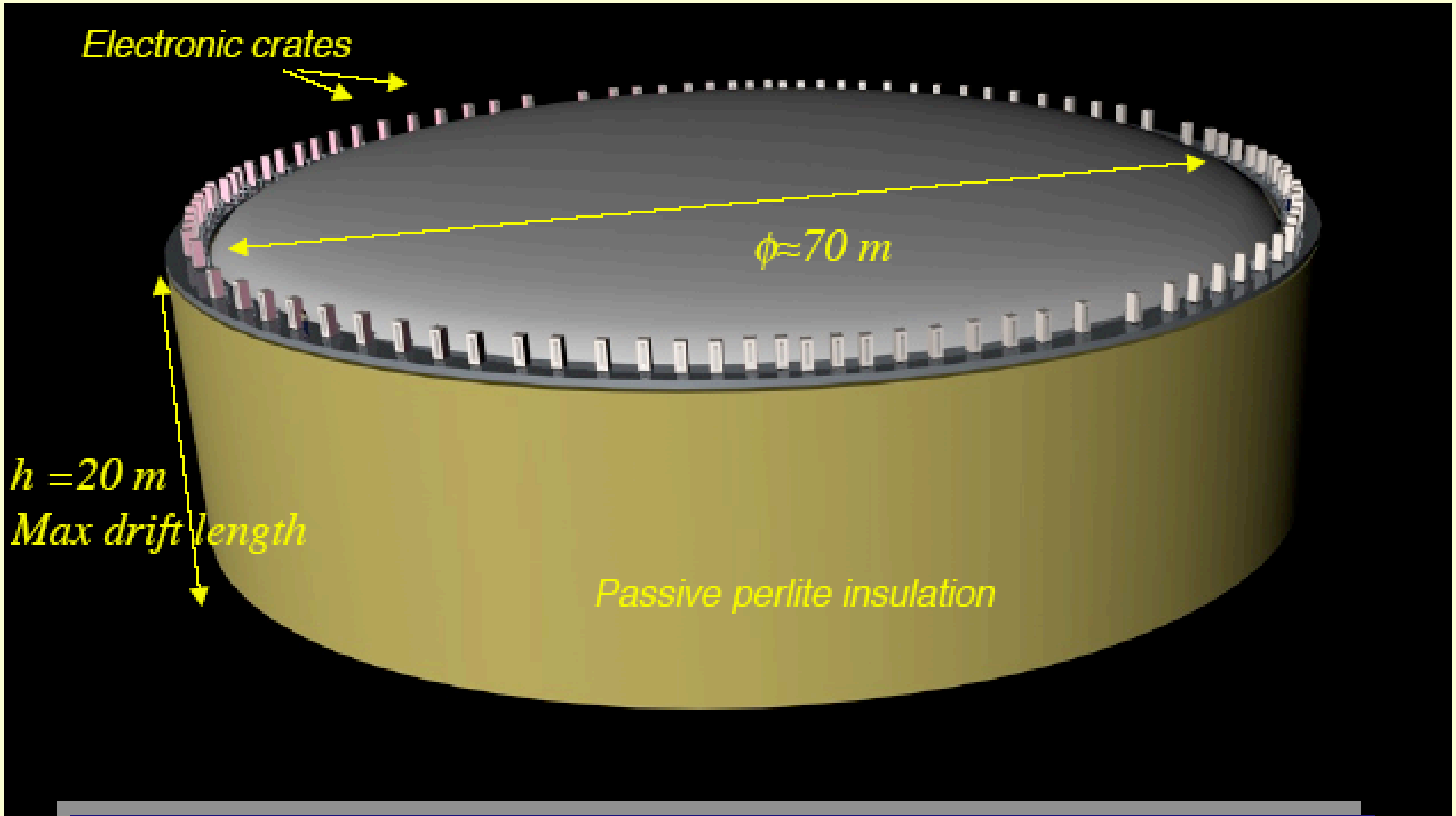
Conceptual design of a ~100 ton LAr TPC for a near station in a LBL facility:



Outer vessel	$\phi \approx$ 5m, L≈13m, 15mm thick, weight ≈ 22 t
Inner vessel	$\phi \approx$ 4,2 m, L ≈ 12 m, 8 mm thick, ≈ 10 t
LAr	Total ≈ 240 t Fiducial ≈ 100 t
Max e- drift	3 m @ HV=150 kV E = 500 V/cm
Charge R/O	2 views, ± 45° 2 (3) mm pitch
Wires	≈10000 (7000) ϕ = 150 μm
R/O electr.	on top of the dewar
Scintill. light	Also for triggering
B-field	possible

The approved T2K experiment in Japan will provide the ideal conditions and high statistical accuracy. Plan to submit EOI for March 2005.

A 100 kton liquid Argon TPC detector



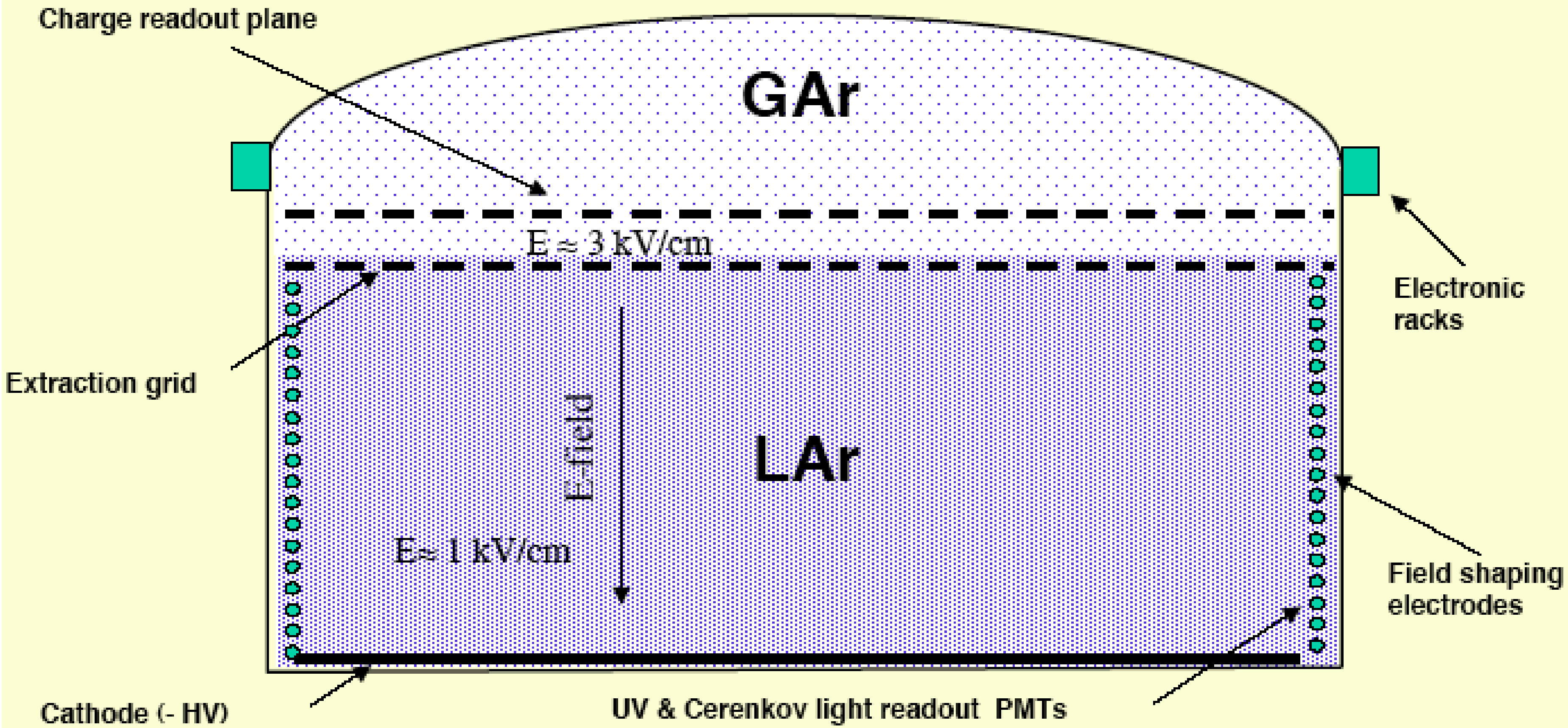
Single module cryo-tanker based on industrial LNG technology

A "general-purpose" detector for superbeams, beta-beams and neutrino factories with broad non-accelerator physics program (SN ν, p-decay, atm ν,

A tentative detector layout

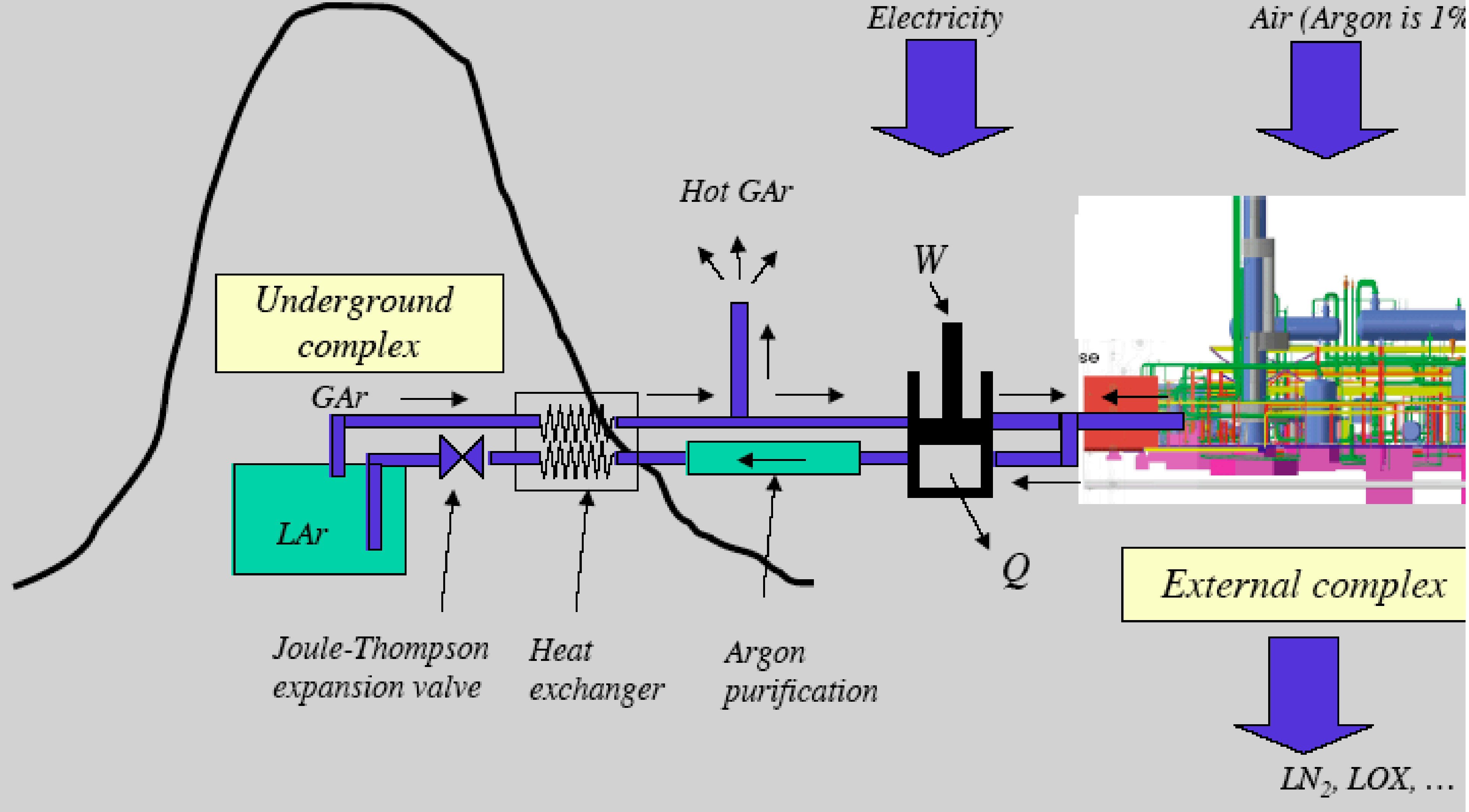
Single detector: charge imaging, scintillation, Cerenkov light

Dewar	$\phi \approx 70$ m, height ≈ 20 m, perlite insulated, heat input $\approx$ 5
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m^3, ratio area/volume $\approx$ 15%
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc $\phi \approx 70$ m located in gas phase above liquid phase
Charge readout electronics	100000 channels, 100 racks on top of the dewar
Scintillation light readout	Yes (also for triggering), 1000 immersed 8" PMTs with
Visible light readout	Yes (Cerenkov light), 27000 immersed 8" PMTs of 20% single γ counting capability



Process system & equipment

- Filling speed (100 kton): 150 ton/day → 2 years to fill, ≈10 years to evaporate !!
- Initial LAr filling: decide most convenient approach: transport LAr and/or in situ cryogenic plant
- Tanker 5 W/m² heat input, continuous re-circulation (purity)
- Boiling-off volume at regime: 30 ton/day: refilling



CP-violation parameters measurement

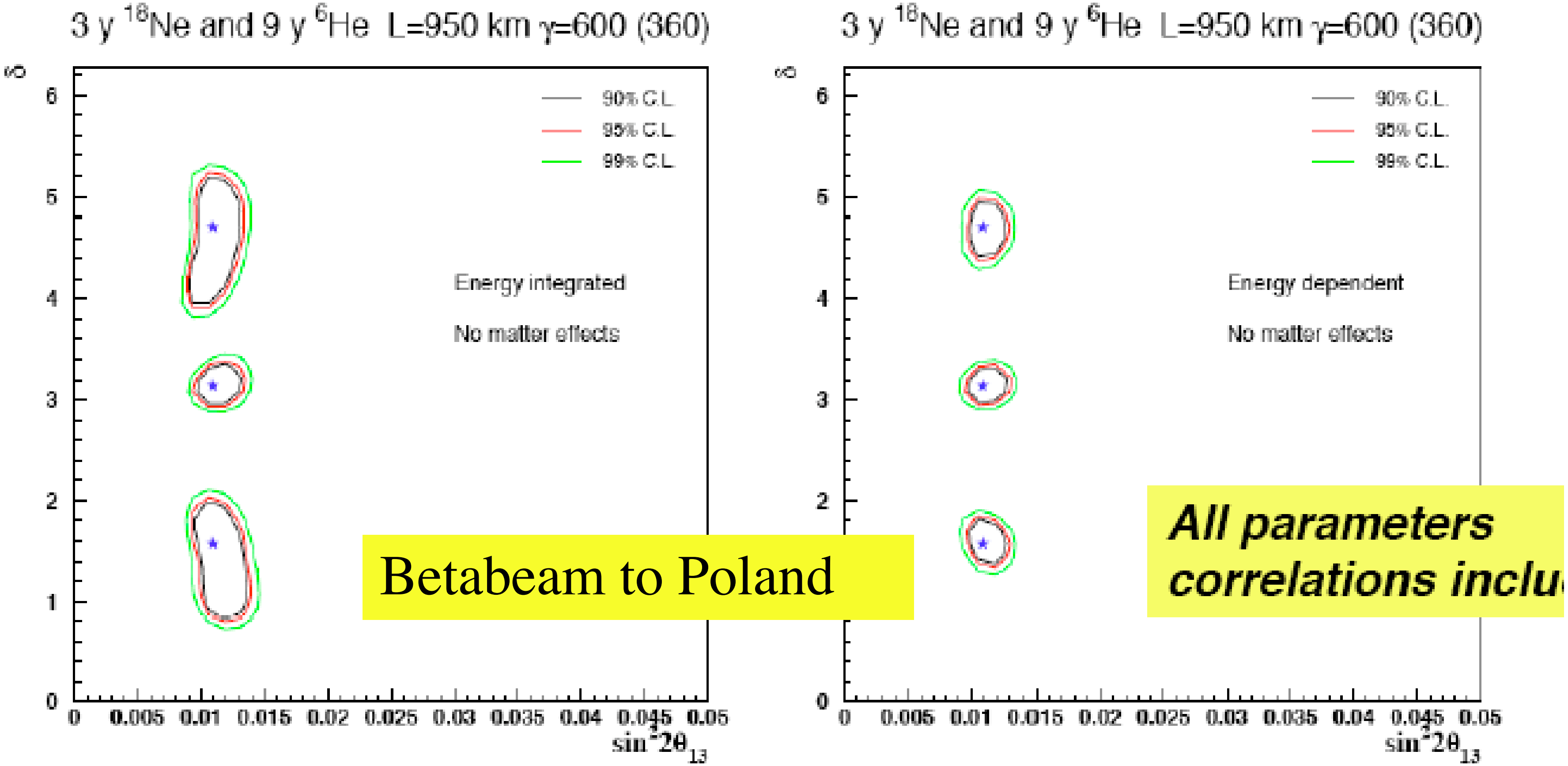
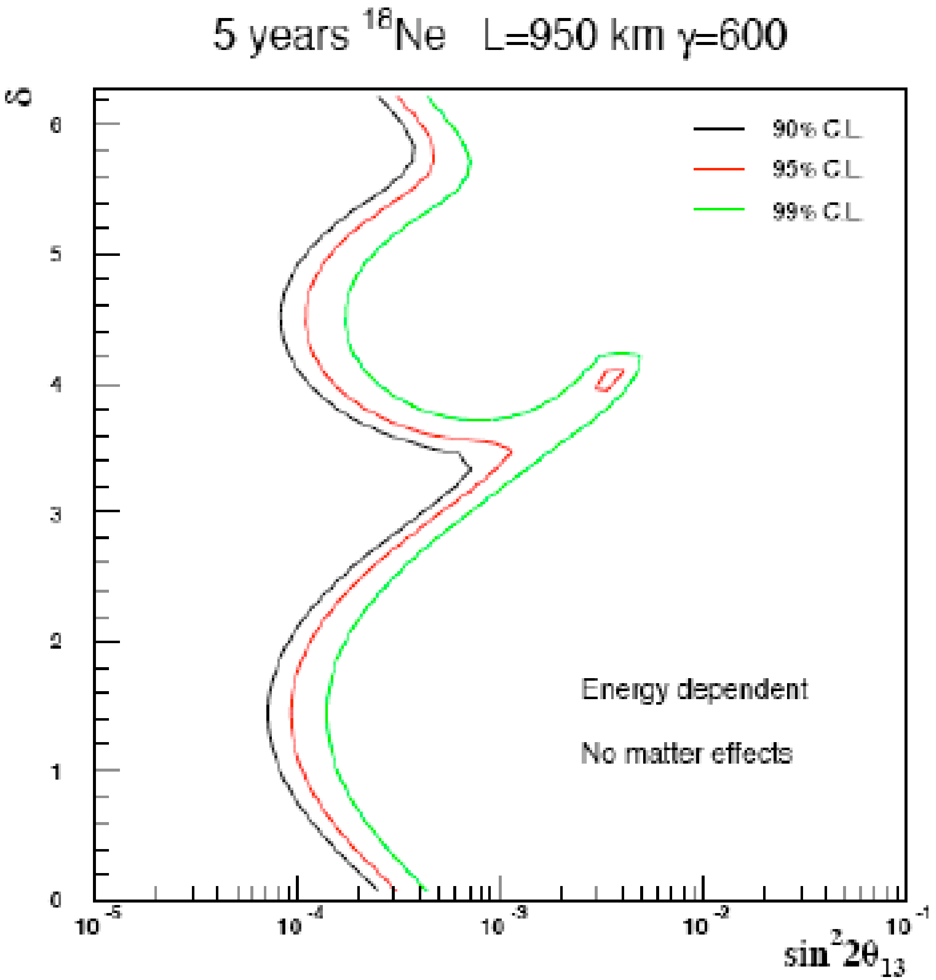
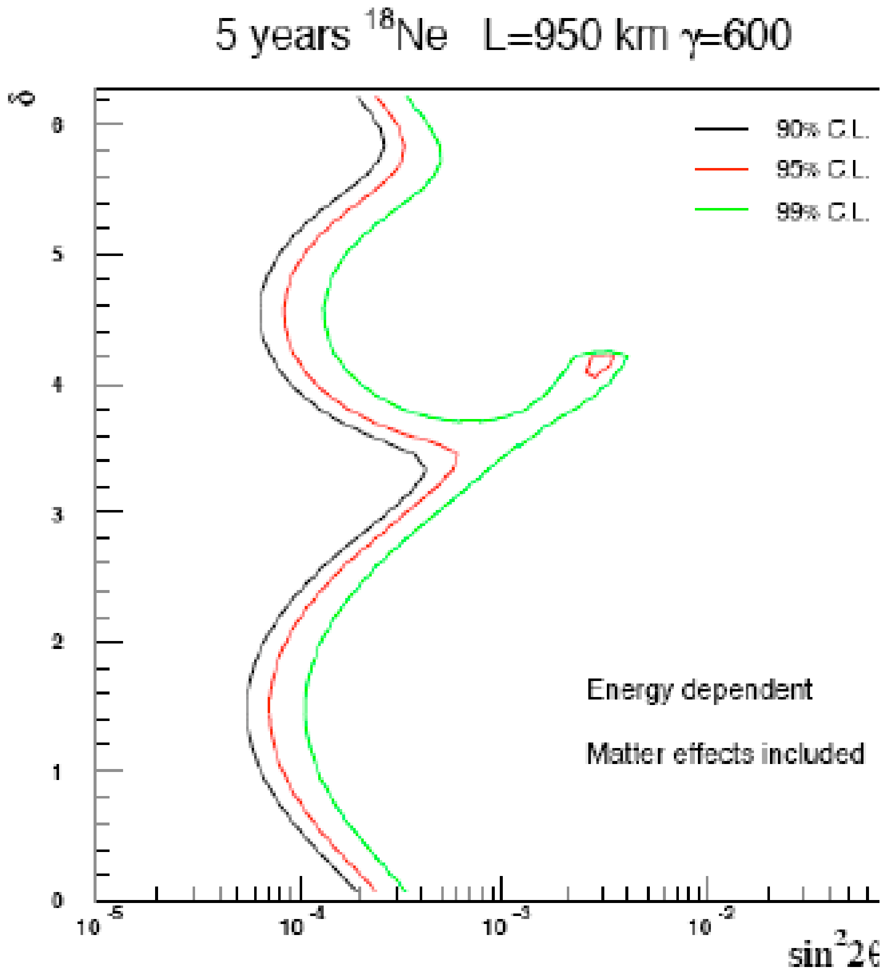


Figure 13: 90%, 95% and 99% C.L. allowed regions on the θ_{13} and δ plane with 3 years of running using a ν_e beam and 9 years with a $\overline{\nu}_e$ beam at L=950 km with a 100 kton detector. Stars indicate the best values of the parameters for every fit. We compare the results non including (left) and including (right) the ν_μ energy dependence in the fit. The expected constraints on the other oscillation parameters from future experiments are considered.

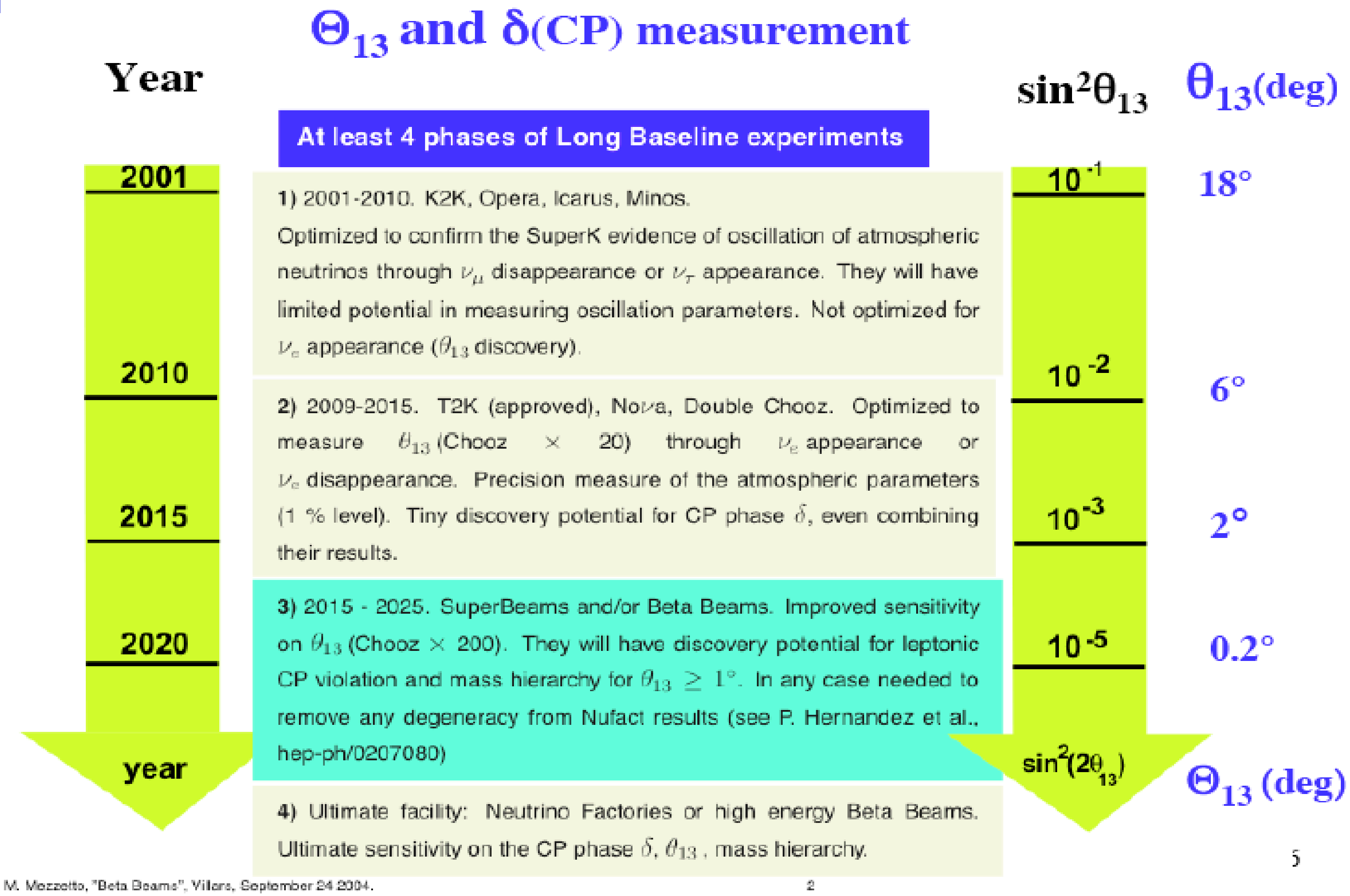
Sensitivity to θ_{13}





Note: after ≈5 years of running, $\nu_e \rightarrow \nu_\mu$ transitions from solar parameters (θ_{12} driv
will necessarily be observed (and possibly larger than those θ_{13} driven).
For the θ_{13} sensitivity shown above, all parameters correlations have been included. Pion background not yet taken into account.

A stepwise approach ("slow train")



1) 2001-2010. K2K, Opera, Icarus, Minos. Optimized to confirm the SuperK evidence of oscillation of atmospheric neutrinos through ν_μ disappearance or ν_τ appearance. They will have limited potential in measuring oscillation parameters. Not optimized for ν_e appearance (θ_{13} discovery).

2) 2009-2015. T2K (approved), Noνa, Double Chooz. Optimized to measure θ_{13} (Chooz $\times$ 20) through ν_e appearance or $\bar{\nu}_e$ disappearance. Precision measure of the atmospheric parameters (1 % level). Tiny discovery potential for CP phase δ, even combining their results.

3) 2015 - 2025. SuperBeams and/or Beta Beams. Improved sensitivity on θ_{13} (Chooz $\times$ 200). They will have discovery potential for leptonic CP violation and mass hierarchy for $\theta_{13} \geq 1°$. In any case needed to remove any degeneracy from Nufact results (see P. Hernandez et al., hep-ph/0207080)

4) Ultimate facility: Neutrino Factories or high energy Beta Beams. Ultimate sensitivity on the CP phase δ, θ_{13}, mass hierarchy.

A stepwise approach ("slow train")

θ_{13} (deg)	$\sin^2\theta_{13}$	Experiments	Years
10°	3.0×10^{-2}	Chooz	< 2000
6°	1.1×10^{-2}	K2K Opera/Icarus	2001-2010
5°	7.6×10^{-3}	Minos	2004-2010
4°	4.9×10^{-3}	Double-Chooz	2007-2012
3°	2.7×10^{-3}	T2K(JHF) Nova	2009-2015
2°	1.2×10^{-3}	Superbeam+Megaton	2015-2025
--> 1°	3.0×10^{-4}	Betabeam+Megaton	2015-2025
0.6°	1.1×10^{-4}		
0.2°	1.2×10^{-5}	Neutrino Factory	> 2025
0.1°	3.0×10^{-6}		

Cost of a Betabeam/Superbeam to Fréjus?

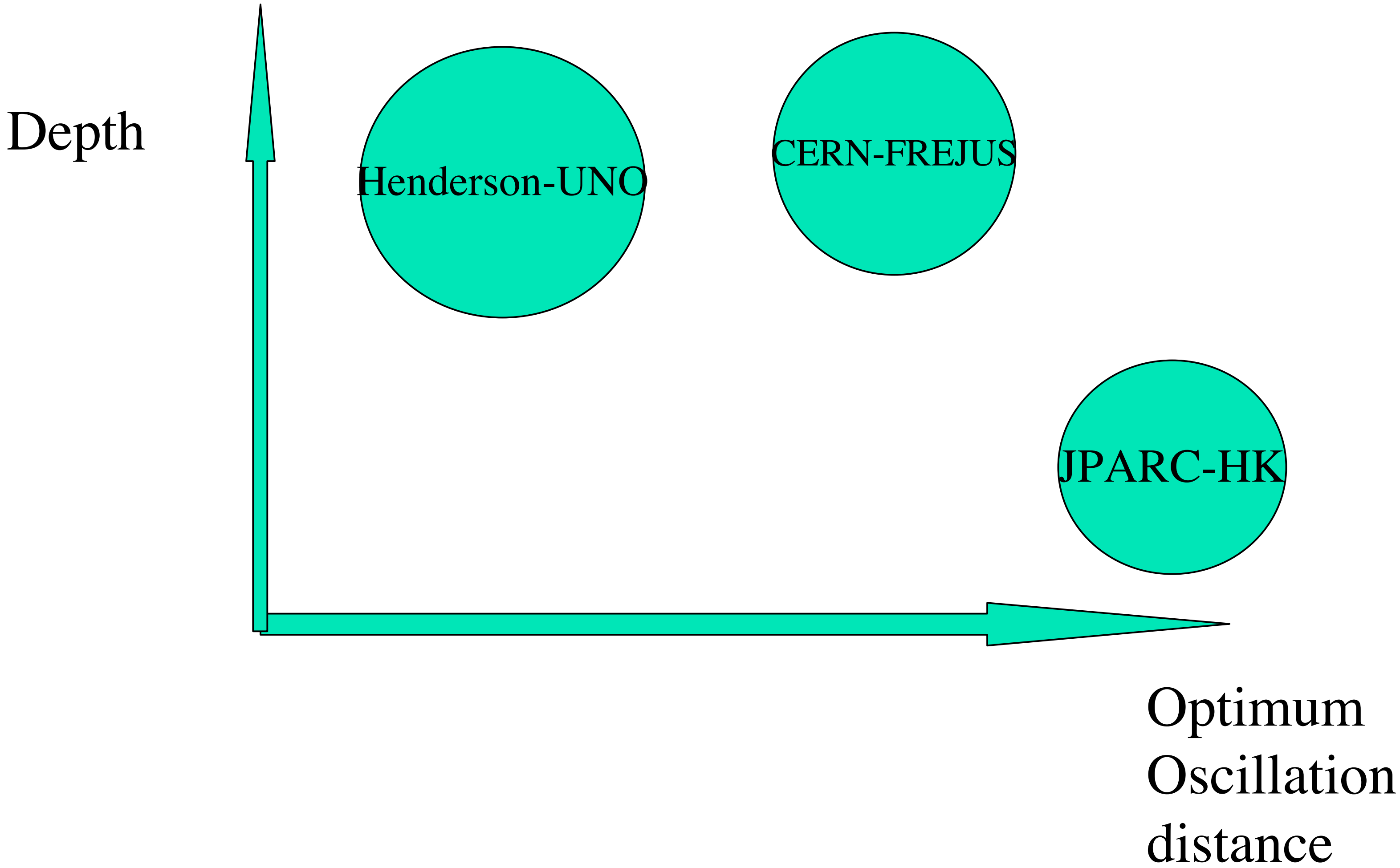
Educated guess on possible costs	USD/CHF	1.60
UNO	960	MCHF
SUPERBEAM LINE	100	MCHF
SPL	300	MCHF
PS UPGR.	100	MCHF
SOURCE (EURISOL), STORAGE RING	100	MCHF
SPS	5	MCHF
DECAY RING CIVIL ENG.	400	MCHF
DECAY RING OPTICS	100	MCHF
TOTAL (MCHF)	2065	MCHF
TOTAL (MUSD)	1291	MUSD

My opinion: Surely optimistic most probably closer to 1.5-2 MUSD

Why 2 beams to the same detector?

- 4 different beams in the **same** detector
- redundancies (CP, T, CPT)
- signal for SB is event bulk for BB (nu-e)
- backgrounds are different (charged π for BB, π^0 for SB)

A first (and biased?) classification of sites




NNN 05
International Workshop on Next Generation of Nucleon Decay and Neutrino Detectors
Aussois – April 7-9, 2005
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F. Wilczek
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S. Wojcicki
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Supernovæ neutrinos
High intensity neutrino beams
Atmospheric neutrinos
Solar neutrinos
Large detector R&D
Engineering of large excavations
http://nnn05.in2p3.fr
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IN2P3
DAPNIA

Conclusions

- A few years of parallel regional effort in dark matter and double beta detectors are still in front of us. Roadmap?
- The next neutrino accelerator and the corresponding detector are in a dynamical situation, but not yer a clear frame of decision, non-accelerator physics and other communities are very important factors
- CERN: towards a decision not later than 2010.
- Three candidate machines (super,beta,factory) complementary expertise in 3 candidate regions. Coordination?

My excuses for being late but I at least have learned 2 lessons I wish to share with you

- I have lost my normal flight, because due to a car accident blocking the road it took me 1.5 hours from the IN2P3 headquarters in Paris to the High Tech Airport of CDG (normally 30 minutes drive)
  - Lesson #1
    - There is no use building a mutibillion infrastructure and let the acces-road to it at a very risky state …or
    - Do not take a risky road to a multibillion infrastructure
- There was no economy -class tickets in the next flight so I was obliged to take business class
  - Lesson #2
    - If you have modest ambitions but you arrive late, you have just wasted taxpayers money
- We should navigate between these two. THANK YOU

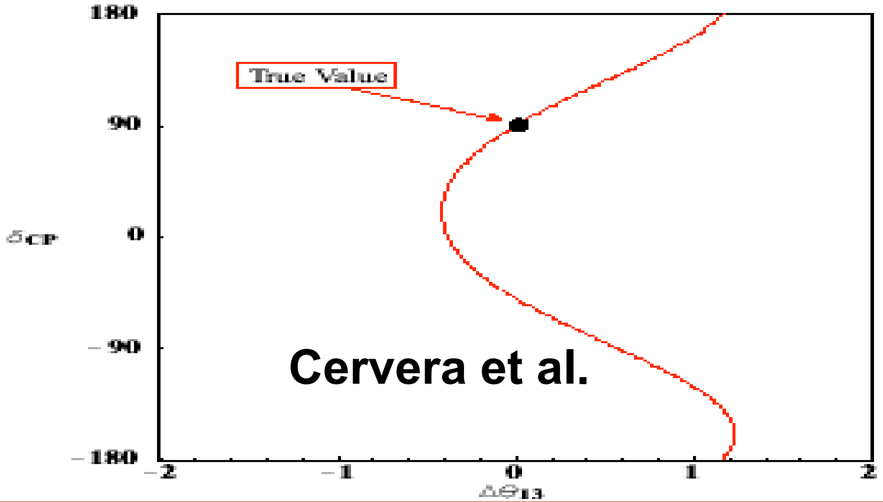
spare

Measurement of θ_{13}. Correlations and degeneracies

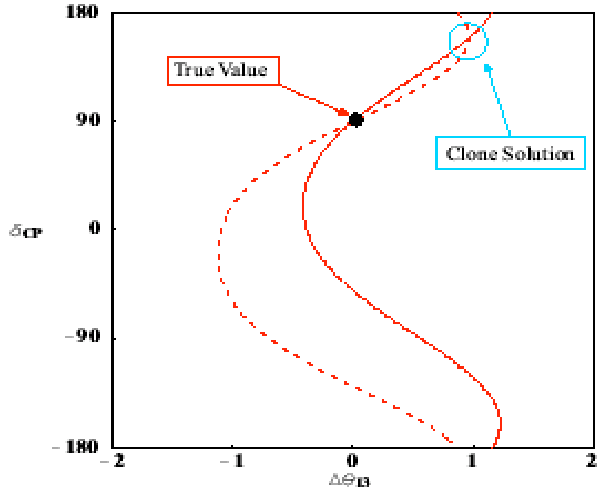
$$P^{\pm}_{\nu_e\nu_\mu}(\theta_{13},\delta) \approx X_\pm \sin^2 2\theta_{13} + \left(Y^c_\pm \cos\delta \mp Y^s_\pm \sin\delta\right) \sin 2\theta_{13} + Z$$

(DeRujula99, Cervera00)

The appearance probability $P(\bar{\theta}_{13},\bar{\delta})$ obtained for neutrinos at fixed (E,L) with input parameters $(\bar{\theta}_{13},\bar{\delta})$ has acontinuous number of solutions



For neutrinos and antineutrinos of the same energy and baseline the system of equations has two solutions the true and energy ependent clone



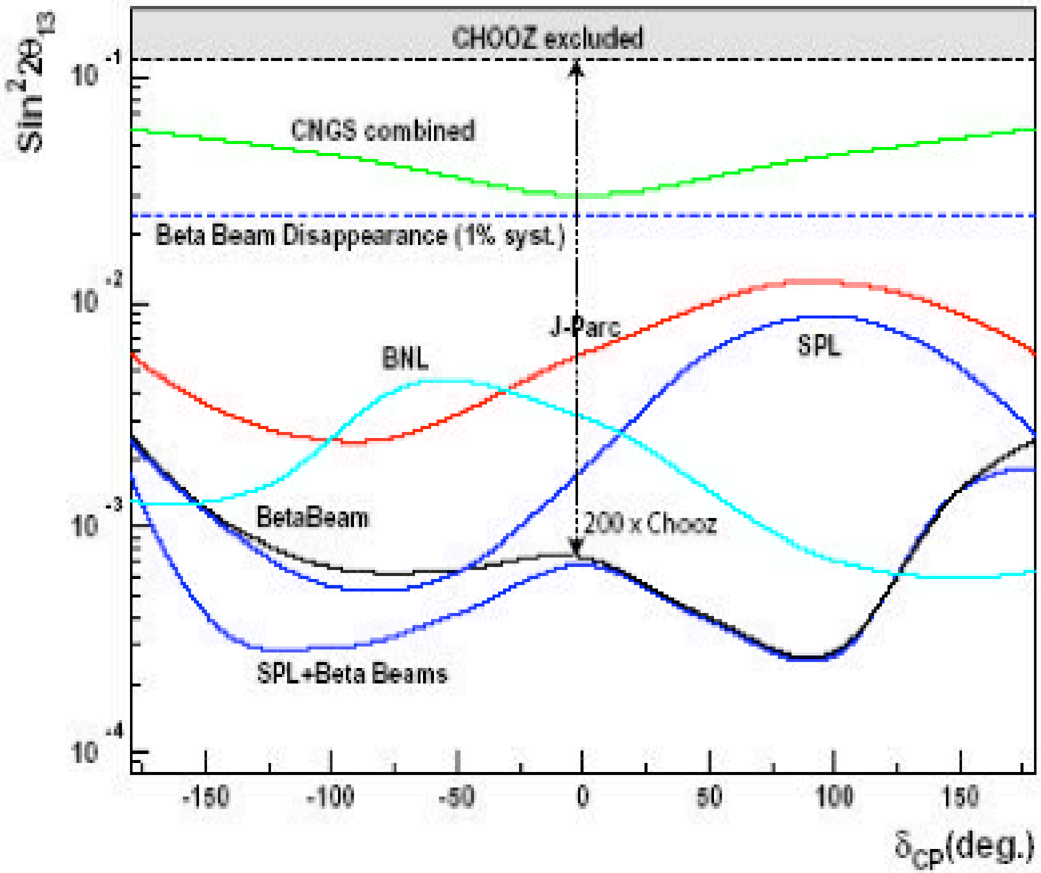
+ Two other sources of degeneracy.

1. Ignorance of the sign of Δm_{23}^2
2. Ignorance of the octant of θ_{23}

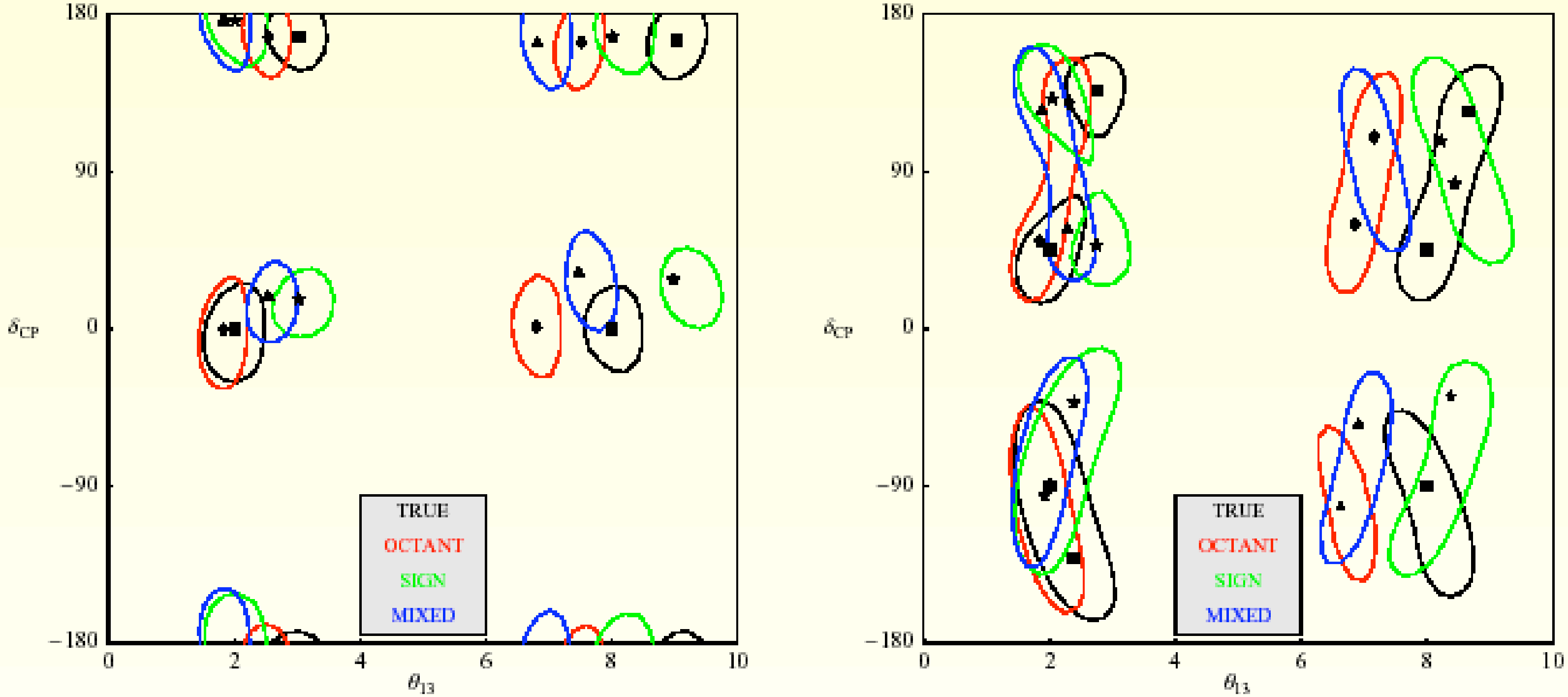
θ_{13} 90 % CL sensitivity

5 years running time, sign(Δm^2)=+1

- Beta Beam can measure θ_{13} both in appearance and in disappearance mode. All the ambiguities can be removed for $\theta_{13} \geq 3.4°$



8-fold Degeneracy in low-gamma BB



- Typical βB Appearance fits for $\theta_{13} = 2, 8$ and $\delta_{CP} = 0, 45, -90$. Backgrounds (see βB table) and Systematics (5%) fully included;
- Eightfold Degeneracy clearly visible (see for example $\theta_{13} = 8$ and $\delta_{CP} = 0$); Induce large uncertainties in θ_{13} (for large θ_{13}) and δ_{CP};

S. Rigolín

How to solve degeneracies

Burguet. Hernández, JJGC

1. Use spectral information on oscillation signals→ experiment with energy resolution
2. Combine experiments differing in E/L (and/or matter effects) → need two experiments
3. Include other flavor channels: silver channel $\nu_e \to \nu_\tau$. Need a tau-capable detector

Donini, Meloni, Migglioazzi, hep-ph/0206034
Donini, Meloni, Rigolin, hep-ph/hep-ph/0312072